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**WORLD MARITIME UNIVERSITY**

Malmö, Sweden

**INVESTIGATION OF MARINE BIOFOULING AND THE  
POSSIBLE NEED TO DEVELOP BIOFOULING  
CONTROL MEASURES IN NIGERIA**

By

**NJIN, RITA NAANDEM**

**Nigeria**

A dissertation submitted to the World Maritime University in partial  
fulfillment of the requirements for the award of the degree of

**MASTER OF SCIENCE**

**In**

**MARITIME AFFAIRS**

**(MARITIME SAFETY AND ENVIRONMENTAL ADMINISTRATION)**

2018

## DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature):



.....

(Date):

18<sup>th</sup> September, 2018

.....

Supervised by:

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Vice President (Academic)  
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### **ACKNOWLEDGEMENT**

My profound gratitude goes to God Almighty, the Creator of the Universe, for seeing me through this programme without hitches. The maritime knowledge and skills I have acquired at the World Maritime University would not have been possible without the kind generosity of the International Transport Workers' Federation (ITF), who found me worthy to be offered a scholarship towards this cause.

I express, without mincing words, my sincere gratitude to my Project Supervisor, Professor Neil Bellefontaine, for his untiring efforts, guidance and constructive suggestions towards the successful completion of this research work.

To the staff, faculty and students of the World Maritime University, particularly the Maritime Safety and Environmental Administration (MSEA) specialization, I say a special thank you for your support in one way or the other throughout my stay in the school and in Malmo, Sweden as a whole.

My unflinching gratitude goes to my husband, Engineer Yila Danlele, for his prayers, patience, love, encouragement and constant support towards the achievement of my goals. I acknowledge tremendously my parents, Honourable & Mrs. Bernard B. Njin, my siblings and in-laws, for their love and moral support during the cause of this Programme.

Finally, I acknowledge the management and staff of the Federal Ministry of Transportation, Nigeria and its Agencies, for finding me worthy to represent the Country towards the quest of making an impact in the maritime industry in Nigeria.

## **ABSTRACT**

Title of Dissertation: **Investigation of Marine Biofouling and the possible need to develop Biofouling Control Measures in Nigeria**

Degree: **Master of Science**

Over the last few decades, the expansion of seaborne trade has risen exponentially. However, the movement of ships from one location to another carries aquatic species to new environments, which eventually becomes an important component of global environmental change. The major modes of invasion related to shipping occur when marine species are carried either in the ballast water of ships or attached to ships' hulls (biofouling). Biological fouling, also known as "Biofouling is described as the undesirable accumulation of microorganisms, plants, algae and animals on submerged structures. Biofouling on ships' hulls causes an increase in roughness, leading to an increase in hydrodynamic drag, which in turn leads to an increase in the rate of fuel consumption and Green House Gas (GHG) emission. In essence, biofouling has a detrimental effect on biodiversity conservation, as well as ecology, health and economy.

This research was aimed at analyzing the potential impact of invasive species on ecosystem biodiversity, assessing the risk of the introduction of Harmful Aquatic Organisms and Pathogens (HAOP) from biofouling and assessing the need for a specific policy to address biofouling in Nigeria. Statistics on maritime traffic, as well as statistics on turnaround time and cargo throughput as a result of the Nigerian port reform of 2006 were used to determine the exposure level and vulnerability of the ecosystem and also to establish the risks to Nigeria.

The need to fully implement the International Convention on the Control of Harmful Anti-Fouling Systems on Ship and the 2011 Guidelines for the Control and Management of ships' biofouling to minimize the transfer of invasive species were recommended as measures to minimize the effects of biofouling. In addition, a recommendation was made for a proposed national biofouling regulatory framework with scientific acceptability and economic feasibility, while noting the importance of having an approved cleaning technique(s) with standardized facilities for ships' hulls and niche areas, approved cleaning zones and technologies.

**KEYWORDS:** Biofouling, Antifouling, Invasive Species, Hydrodynamic Drag, Biodiversity

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## **LIST OF ABBREVIATIONS**

ANFs	Adhesive Nanofibers
AFS	Antifouling System
AFS Convention	International Convention on the Control of Harmful Antifouling System on Ship
CBD	Convention on Biological Diversity
CO <sub>2</sub>	Carbon Dioxide
COMNAP	Council of Managers of National Antarctic Programs
CRMS	Craft Risk Management Standard
ECOWAS	Economic Community of West African States
EEZ	Exclusive Economic Zone
EPS	Extracellular Polymeric Substances
FGN	Federal Government of Nigeria
GCLME	Guinea Current Large Marine Ecosystem
GEF	Global Environment Facility
GHG	Green House Gas
GISP	Global Invasive Species Programme
GLOBALLAST	Global Ballast Water Programme
GLOFOULING	Global Biofouling Programme
GLOMEEP	Global Maritime Energy Efficiency Partnership
HAOP	Harmful Aquatic Organisms and Pathogens
IAS	Invasive Aquatic Species

IMarEST	Institute of Marine Engineering, Science & Technology
IMO	International Maritime Organization
ISO	International Organization for Standardization
ITCP	Integrated Technical Cooperation Programme
LMEs	Large Marine Ecosystems
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee
MISP	Marine Invasive Species Program
NIMASA	Nigerian Maritime Administration and Safety Agency
NMTP	National Maritime Transport Policy
NPA	Nigerian Ports Authority
ROs	Recognized Organizations
ROV	Remotely Operated Vehicle
SEEMP	Ship Energy Efficiency Management Plan
SOA	Seaweed of Alaska
TBT	Tributyltin
TOM-SIMS	Time of Flight-Secondary Ion Mass Spectrometry
TWAP	Transboundary Waters Assessment Programme
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme

UNIDO	United Nations Industrial Development Organization
US	United States

## **1 INTRODUCTION**

### **1.1 Background of the study**

Over the last few decades, the expansion of seaborne trade has risen exponentially. However, the movement of ships from one location to another carries aquatic species to new environments (IMO, 2017). According to Simberloff et al., 2013 (As cited by Chan & Briski, 2017), the introduction and establishment of invasive species outside their native environment is an important component of global environmental change. Although only a small proportion of species introduced are able to establish and become invasive, their impact can still be detrimental. This is because they have the ability to cause a decline or extinction of the native species, contribute to the transmission of pathogens, disrupt ecosystem services/functions and cause substantial damage to natural resources. The invasion of these aquatic species in new environments by ships is said to be a serious threat to the oceans and biodiversity conservation (IMO, 2017). The alarming rate of such invasions in marine and coastal ecosystems worldwide is largely attributed to human activities such as shipping, aquaculture, habitat modification, fisheries and climate change (Chan & Briski, 2017).

According to Dukes and Mooney, 1999 (As cited by Sorte, Williams & Zerebecki, 2010), there is evidence that alien species have a wider range in latitude than native species, hence the reason for their ability to withstand different ranges of environmental conditions and extreme temperatures (IMO, 2017).

The major modes of invasion related to shipping occur when marine species are carried either in the ballast water of ships or attached to ships' hulls. Biological fouling, also known as biofouling, "is described as the undesirable accumulation of microorganisms, plants, algae and animals on submerged structures (especially

ships' hulls)" (IMO, 2017). A wide range of transportable, sessile, and sedentary organisms colonize hull surfaces and can dislodge and/or reproduce at the subsequent ports-of-call (Chan, MacIsaac & Bailey, 2016). Ballast water on the other hand is defined as "water with its suspended matter taken on board a ship to control trim, draught, stability or stresses of the ship" (Kim, 2013). As documented by Drake & Lodge, 2007 and cited by Bouyssou & Madjidian, 2013, some scientists regard biofouling as presenting a higher risk of invasive species introduction than ballast water. In New Zealand, 70 percent of aquatic invasive species were introduced through fouling against 3 percent through ballast water; while in Port Phillip Bay, Australia, about 80 percent of invasive species were introduced from ships' hulls against 20 percent from ballast water; and in American waters, 35 percent of invasive species were introduced through hull biofouling against 20 percent from ballast water (MarEx, 2017).

The International Maritime Organization (IMO), the Convention on Biological Diversity (CBD) and many United Nations Environment Programme (UNEP) Regional Seas Conventions have recognized the possibility of alien aquatic species transferred through Biofouling to be harmful (IMO, 2017). There are about 4000 species of marine fouling (Bouyssou, 2011). According to Yebra, Kiil & Kim, 2003 (As cited by Noufal & Hassan, 2016), Biofouling is present everywhere in the marine environment and it is a serious issue for the shipping industry. It has a negative effect on the ecology (changing competition between species, predation and population changes in sensitive areas), human health and the economy (affecting fisheries and tourism, and damaging infrastructure).

Biofouling on ships' hulls causes an increase in roughness, leading to an increase in hydrodynamic drag as the vessel is in motion in water. As a result of Biofouling, there is an increase in the rate of fuel consumption, cleaning of ships' hulls, coating and environmental compliance measures (Callow & Callow, 2002). The increase in fuel consumption as a result of Biofouling certainly has an effect on the environment.



In support of MARPOL Annex VI Chapter 4 on Ship Energy Efficiency Management Plan (SEEMP), the IMO developed a guideline within which hull maintenance is clearly identified as affecting the energy efficiency of ship operations. It established that “hull resistance can be optimized by new technology-coating systems, possibly in combination with cleaning intervals. Regular in-water inspection of the condition of the hull is recommended”. Furthermore, it is stated that the cleaning and polishing of a ships’ propeller or the right coating may increase fuel efficiency. Moreover, the timely full removal and replacement of underwater paint to prevent roughness of the hull should be considered (IMO, 2012).

Biofouling can be microfouling and macrofouling. When a clean surface is immersed in water, it absorbs a molecular ‘conditioning’ film, which consists of dissolved organic material. Bacteria, algae and cyanobacteria all colonize within hours forming a biofilm known as microfouling or slime. Soft fouling (including algae, soft corals, sponges and hydroids) or hard fouling (invertebrates such as mussels, tubeworms and barnacles) make up the macrofouling, which may develop and overgrow the microfouling. The substratum, geographical location, season, predation and competition amongst others, are factors that determine the various types of organisms that develop in a fouling community (Callow & Callow, 2002).



**Figure 1 Biofouling on a ships' hull**

(Source: <http://www.seos-project.eu>)

In order to eliminate or reduce the risks of non-native species introduction, ship hulls need to be coated. In the early days of shipping, the use of lime and later arsenic to coat ships' hulls was effective in preventing the attachment of unwanted organisms. As time evolved, modern chemical industries developed an effective Anti-Fouling paint by using metallic compounds (IMO, 2017). According to the Council of Managers of National Antarctic Programs (COMNAP), 2006 (As cited by Noufal & Hassan, 2016), anti-fouling paints containing organotin like Tributyltin (TBT), a Biocide, were used in the late 1960s on ships' hulls to prevent sea life from attaching themselves. The use of paints containing TBT was, however, proven to deform oysters and cause sex changes in whelks. They were also found to be harmful to sea life and the environment and had the possibility of entering the food chain (IMO, 2017). The IMO in 2001, adopted the "International Convention on the Control of Harmful Anti-Fouling System on Ship" (AFS Convention) with the sole aim of protecting the marine environment and human

health from the effects of the chemicals contained in Anti-Fouling Systems. The Convention came into force in 2008 (Anti-Fouling Systems, 2001).

With the negative effects of Biofouling, it became imperative to abate the transfer of invasive species in order to manage Biofouling in a consistent manner. IMO, in 2011, through its Marine Environmental Protection Committee (MEPC), adopted “*The Guidelines for the control and management of ships’ biofouling to minimize the transfer of invasive aquatic species* (Biofouling Guidelines)”. In order to assist Member States and Observers wanting to collect information for further reviews in the future, IMO prepared a Guidance, approved by the MEPC in 2013 for evaluating the 2011 Biofouling Guidelines (IMO, 2017).

## **1.2 Aim and Objectives of the Study**

The aim of this research work is to investigate the risks of Biofouling in Nigeria. Nigeria is a tropical country and there are reports that more research has been carried out in temperate regions than in the tropical regions. It is, therefore, necessary to understand the exposure of Nigerian ports to biofouling and the vulnerability of the Nigerian ecosystem. The specific objectives are:

- i. To analyze the potential impact of invasive species on ecosystem biodiversity in the context of Nigeria;
- ii. To assess the risk of the introduction of Harmful Aquatic Organisms and Pathogens (HAOP) from Biofouling; and
- iii. To assess the need for a specific policy to address Biofouling in Nigeria.

## **1.3 Research Methodology**

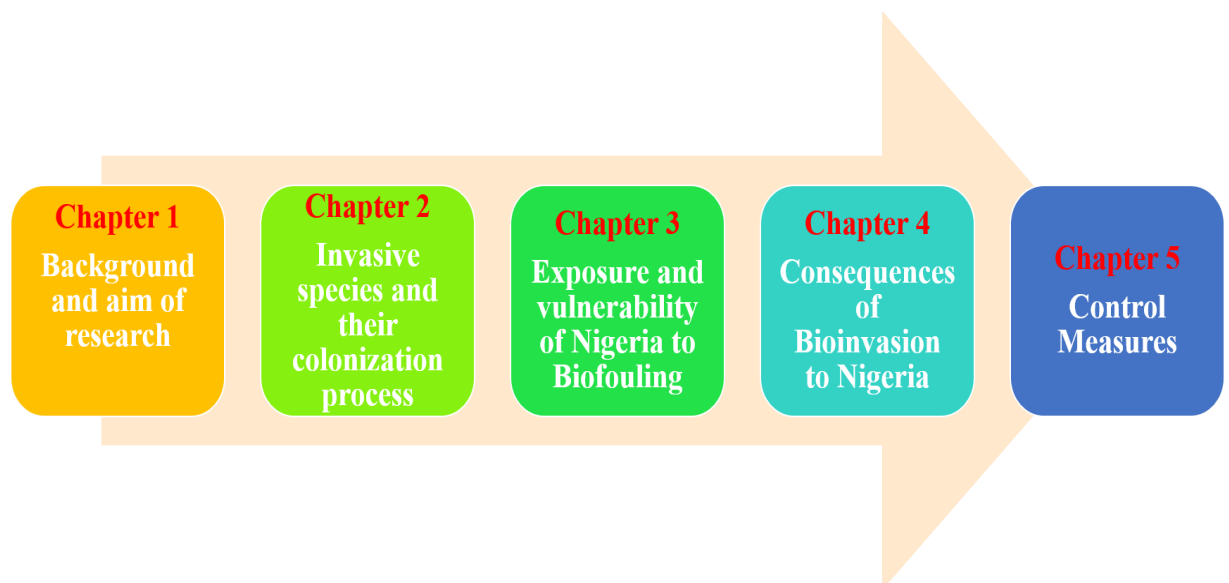
For the purpose of this research work, Nigerian seaports were used as a case study. In order to assess the exposure of Nigeria to the invasion of alien species in the marine environment, data was collected from the major ports located in the South-West (Western Ports) and South-South (Eastern Ports) regions of Nigeria through the Nigerian Ports Authority (NPA). Statistics on maritime traffic of ships going in and out of the major ports were analyzed to determine the exposure of Nigeria to Biofouling. The risk approach was used to conduct a risk assessment in the context

of Biofouling in Nigeria. Biogeographic origin of vessels' last port of call as well as the maximum and minimum amount of time vessels spend in the ports (vessels residence time) was also analyzed.

In the course of the research, the vulnerability of the ecosystem was also assessed by looking at evidence of invasive alien species provided in literature of research works in the tropical region, noting that if the risk turns out to be high, a recommendation on the need to develop control measure(s) will be proposed. This recommendation will include assessing the cleaning methods of the ships' hulls (involving the level of fouling, cleaning techniques, facilities used for cleaning, the zones permitted or not allowed for cleaning and the technologies accepted).

#### 1.4 Research Structure

Figure 2 summarizes the approach to investigating biofouling in Nigeria in a simplified manner.



**Figure 2 Schematic Representation of the structural approach**

(Source: Author)

Chapter One (1) of this research gives an overview of Biofouling, and, according to different reports, its level of devastation compared to invasive species from Ballast

Water. The major aim of the research is also highlighted with the specific objectives to achieve the aim also clearly spelt out.

Chapter Two (2) shows the physiological principles of aquatic organisms, indicating their use of energy and carbon for classification purposes. This chapter also discusses the main organisms known to foul vessel hulls and further indicates the organisms that are specifically known to be associated with the tropical regions (since the subject of the case study, Nigeria, is a tropical country). In this chapter, the mechanism of action for adhesion of organisms to vessels and their colonization process is also discussed, along with factors influencing marine growth on ships.

Chapter Three (3) attempts to explain the Nigerian port system, and its pre and post concession achievement looking at the statistics of cargo throughput, turnaround time and maritime traffic. The trading regions, and invasion in other tropical regions are also discussed to establish the vulnerability of the Nigerian ports.

Chapter Four (4) describes bioinvasion in the Guinea Current Large Marine Ecosystem. Furthermore, it gives an insight into the impact of invasive species to the ecology, economy, health and energy efficiency. It also discusses risk assessment based on vessels' residence time and last port of call.

Chapter Five (5) explains in detail, the control measures already employed to tackle the menace of invasive species and the possibility of developing a policy in Nigeria on Biofouling control.

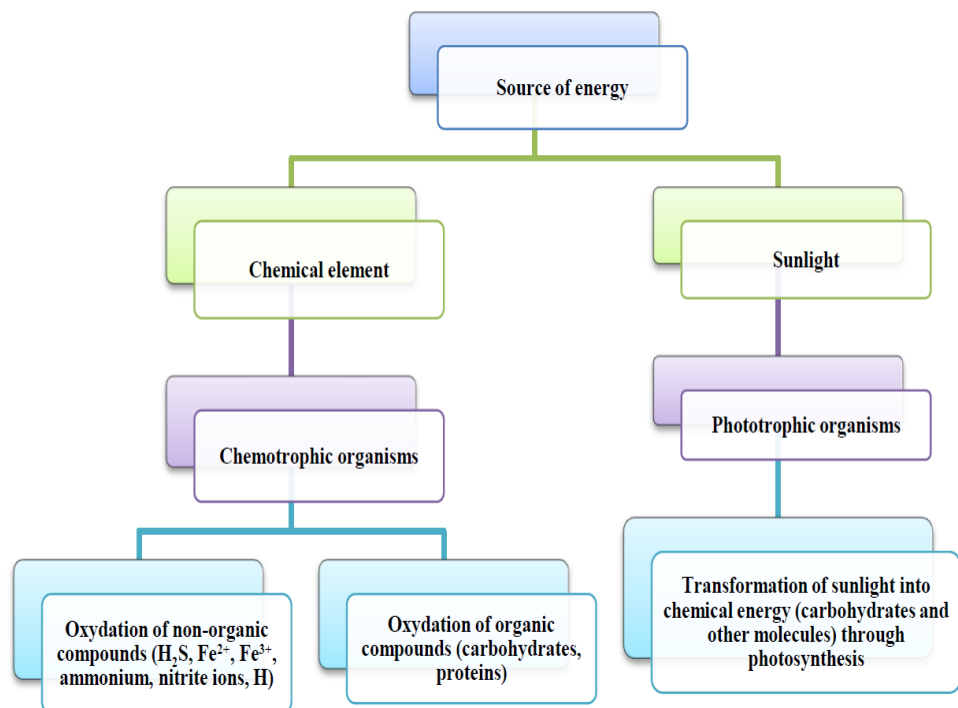
Chapter Six (6) provides the overall conclusions of the research from this study.

## 2 THE INTRODUCTION OF INVASIVE SPECIES BY SHIPS

Aquatic organisms are generally of unique functions, activities and properties. Their basic physiological principles, characteristics and adhesion mechanisms aid in differentiating them and allow for a better understanding. Their different characteristics are what make management in a universal manner challenging.

### 2.1 Physiological Principles of Aquatic Organisms

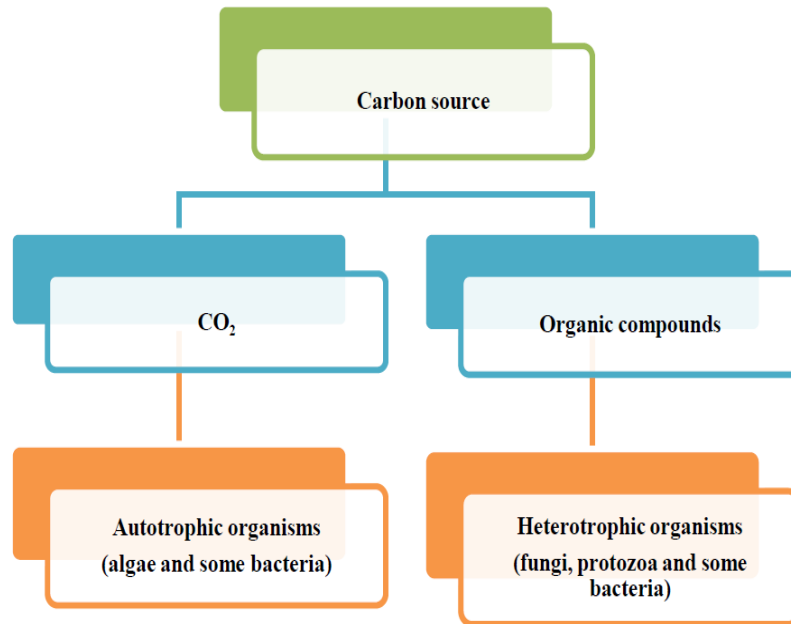
Figure 3 shows the group of organisms that require a source of energy for their existence. The organisms in this group are divided into chemotrophic organisms (oxidizing chemical compounds) and phototrophic organisms (energy from sunlight).



**Figure 3 Energy use as a means of classifying organisms**

(Source: Ekenstierna, 2003 as cited by Bouyssou, A., 2011)

Figure 4 shows the group of organisms that require a carbon source for their existence. The organisms in this group are divided into autotrophic organisms (producers, self-feeding from Carbon Dioxide) and heterotrophic/organotrophic organisms (consuming organic compounds).



**Figure 4 Carbon use as a means of classifying organisms**

(Source: Ekenstierna, 2003 as cited by Bouyssou, A., 2011)

### 2.3 Main Fouling Organisms

Fouling organisms are diverse and usually depend on factors such as water depth, water quality, geographical zone, current, number of propagules, nature of substrate surface and competitors. Below are the key fouling groups of organisms that have been reported by Salta, et al. (2009):

- a) **Barnacles:** they are classified into the phylum, 'Arthropoda' and class, 'Crustacea' with about 12,000 species currently known. These are usually found in the marine environment in shallow and tidal waters. They are said to have a distant relationship with crabs and lobsters. Barnacles encrust by

attaching themselves permanently to hard substrate. They are sessile suspension feeders with a distinct larval stage.



**Figure 5 *Balanus modestus***

(Source: Salta, et al; 2009)

- b) Algae:** Algae are quite a diverse group as there are Green, Brown and Red algae. Green Algae belongs to the phylum, 'Chlorophyta' and class, 'Chlorophyceae'; Brown Algae belongs to the phylum, 'Ochrophyta' and class, 'Phaeophyceae'; and Red Algae belongs to the phylum, 'Rhodophyta' and class, 'Florideophyceae'. They are autotrophic in nature, existing as either unicellular or multicellular organisms. The multicellular forms are macrofoulers and most times referred to as seaweeds. Algae are photosynthetic and eukaryotic.



**Figure 6 *Ulva sp.***

(Source: Salta, et al; 2009)



- c) **Sea squirts or Ascidians:** These belong to the phylum, 'Tunicata and class, 'Ascidiaceae'. Ascidians can be found globally, especially in shallow waters having a salinity of over 2.5%. They are sack-like invertebrates as seen in Figure 7. Most sea squirts are sessile animals.



**Figure 7 *Ciona sp.***  
(Source: Salta, et al; 2009)

- d) **Bryozoans or Sea mats:** While these organisms belong to the phylum, 'Ectoprocta Bryozoa', they belong to various classes. Bryozoans can come together in their millions and form one colony (less than one millimeter in length) as seen in Figure 8. A zooid is usually found in tiny openings on the skeletons. Bryozoans are mostly sessile, having a global distribution, but more are prominent in shallow and warm waters in tropical regions.



**Figure 8 *Bugula neritina***

(Source: Salta, et al; 2009)

- e) **Mussels:** These belong to the phylum, 'Mollusca' and class, 'Bivalvia'. They are found in both freshwater and saltwater habitats. Filter feeders, clams or bivalve molluscs are mussels. Often times, mussels mean edible bivalves of the family, 'Mytilidae', mostly found on exposed shores in intertidal zones, attached by using their strong byssal thread or beard to a firm substrate. Some of the species belonging to the genus, 'Bathymodiolus' are known to colonize hydrothermal vents which are associated with deep ocean ridges. Marine mussels are asymmetrical in shape (see Figure 9) with dark brown, blue or blackish shell colour.



**Figure 9** *Brachidontes exustus*  
(Source: Salta, et al; 2009)

- f) **Hydroids:** Hydroids are of the phylum, 'Cnidaria' and class, 'Hydrozoa'. Jellyfish, sea anemones, sea wasps and sea pens also belong to the Cnidaria phylum. This phylum is said to contain about 9,000 species of animals (one of which is seen in Figure 10), especially in the marine environment. They are corals and an important source of reef builders. Most hydroids are colonial.



**Figure 10** *Leptogorgia hebes*

(Source: Salta, et al; 2009)

- g) Serpulids:** Belonging to the phylum, ‘Annelida’ and class, ‘Polychaeta’, serpulids are commonly referred to as tubeworms (see Figure 11). They are filter feeders who secrete tubes of Calcium Carbonate. They usually possess a special operculum which blocks the entrance of their tubes when they withdraw into the tubes.



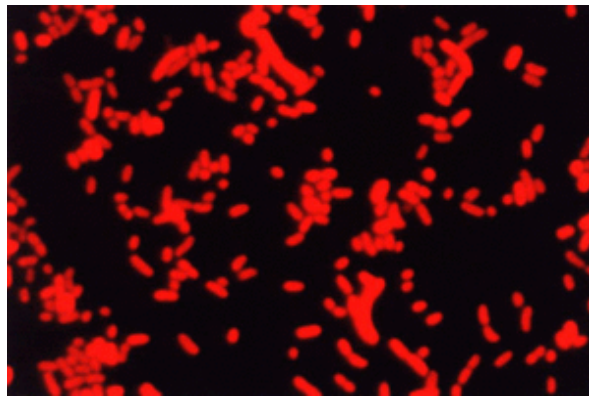
**Figure 11** *Pomatoceros triqueter*

(Source: Salta et al; 2009)

## **2.4 Some Fouling Organisms in the Tropics**

- a) Cyanobacteria (*Synechococcus sp.*):** *Synechococcus sp.* as shown in Figure 12 are cyanobacteria that are able to carry out oxygenic photosynthesis. They are known for causing destructive blooms, thereby producing neurotoxins, and

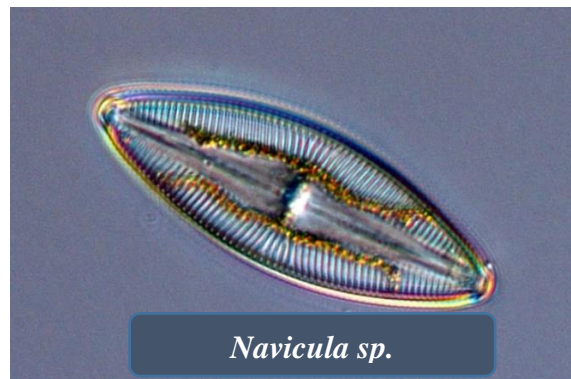
their stench is very oppressive. Concentrations of metals such as phosphorus or iron and nutrients can limit their growth. Most genera of cyanobacteria are indicators of eutrophication. These organisms are motile and do not possess flagella. They possess a unique biochemical pigment known as phycoerythrin, whose orange fluorescence helps in its identification. They can also be found in abundance in temperate regions during autumn and summer (Microbewiki, 2010).



**Figure 12 *Synechococcus sp.***

(Source: [Russian Academy of Sciences.](#))

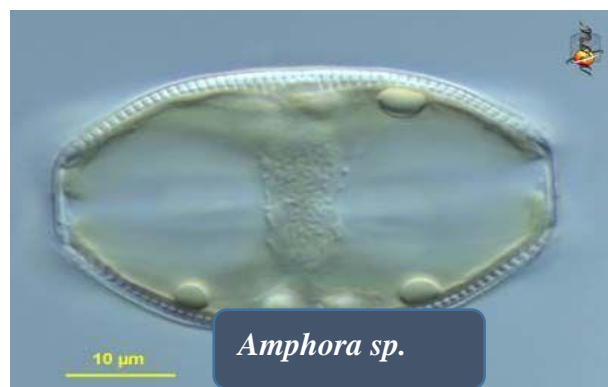
- b) Diatoms (*Navicula sp.* and *Amphora sp.*):** Some diatoms are benthic microalgae which produce mucilage that helps in binding them to their substrate. The genus, *Navicula*, are benthic diatoms, having the ability to produce polysaccharides (Fimbres-Olivarria et al., 2016). *Navicula sp.* as seen in Figure 13 are photosynthetic and have the ability to reproduce sexually and asexually. Aside from being found in the benthic habitat, they can also be found in plankton. They are present everywhere throughout the year, but are more abundant in spring and fall in the temperate region. They are not known to form blooms (Phytoplankton Encyclopedia, 2012).



**Figure 13 *Navicula sp.***

(Source: The Phytoplankton Encyclopedia Project, 2012)

*Amphora sp.*, on the other hand (see Figure 14), are an important genus of the marine and freshwater diatoms. There are over 1000 species of Amphora (John & Hodkinson, 2007). Amphoroid diatoms can be seen with the light microscope by their dorsiventral frustules (Sato, Tamtosu & Mann, 2013).



**Figure 14 *Amphora sp.***

(Source: [micro\\*scope](#) Bahr, M. & Patterson, D.)

- c) **Algae (*Ulva sp.*):** The genus *Ulva* is also referred to as “Sea Lettuce”. It can be found in both marine and freshwater habitats, and is distributed worldwide. With changing environmental conditions, they can change their habitat from tube-form to blade-form or vice versa. There are indications that phylogeographic assessments of *Ulva* have been done in countries including Japan, USA and China. In India, *Ulva* has been extensively subjected to

taxonomic examination (Bast, John & Bhushan, 2014). The species, *Ulva intestinalis* in Figure 15 is quite relevant as a biofouling organism. It is a bright green seaweed (green alga) that is found in abundance during the summer but decays and forms masses of bleached white fronds at the end of the season. It possesses flagella, which could be naked or covered with hairs or scales (SOA, 2013).



**Figure 15** *Ulva intestinalis*

(Source: Seaweed of Alaska, SOA, 2013)

- d) Mollusca (*Mytilus edulis*):** It is also referred to as the “common blue mussel” and scientifically classified as a bivalve mollusc. *Mytilus* species have been widely reviewed over a period of time by different scientists due to their economic importance, widespread distribution, and significance as biomonitors and ecological engineers. *Mytilus edulis* as seen in Figure 16 has the ability to tolerate a wide habitat range/ecological conditions found in oceanic, high intertidal, warm, estuarine and iced environments (CABI, 2018).





**Figure 16 *Mytilus edulis***

(Source: <https://www.google.se/search?sa=X&q=Blue+mussel&stick>)

- e) **Barnacles (*Balanus sp.*):** They are also known as “Acorn Barnacles” and are found attached to man-made structures or mangroves. They usually assemble around the lower parts of the intertidal area. They possess a conical shell, which helps in redirecting wave energy in order not to dislodge. They feed on planktons and play a vital role in the provision of food for many molluscs and crabs (Chian, 2018). A prevalent biofouler of ships and harbor structures is the species known as *Balanus Amphitrite* (see Figure 17). It is commonly known as a “Striped Barnacle”. They are sessile barnacles, filter feeders and have vertical purple stripes on their capitulum plates (a protective rigid plate). They appear in a conical shape with diamond-shaped openings. They are known fouling organisms dominant worldwide in both the tropics and temperate waters. *B. Amphitrite* spawns throughout the year in subtropical regions and during the spring or summer in temperate regions.



**Figure 17 *Balanus amphitrite***

(Source: [https://www.sms.si.edu/irlspec/Balanus\\_amphitrite.htm](https://www.sms.si.edu/irlspec/Balanus_amphitrite.htm))

- f) **Bryozoa (*Bugula neritina*):** They appear as dull dark red to purple or purple to brown organisms. They are usually mistaken to be seaweeds because they grow upright in somewhat bushy and branching tufts. They are hermaphrodites but do not self-fertilize because their eggs are released towards the middle of their life span, and sperm at the end. Their settlement on hard surfaces occurs in late fall to early spring in tropical waters and in summer and fall in temperate waters. They feed with the aid of tentacles known as lophophore. *B. neritina* as seen in Figure 18 is a prevalent fouler in Hong Kong and commonly found on seagrasses, mangrove roots, oyster shells and algae in the Caribbean. They are sometimes found in abundance on vessel hulls and intake pipes of ships (Cohen, 2011).





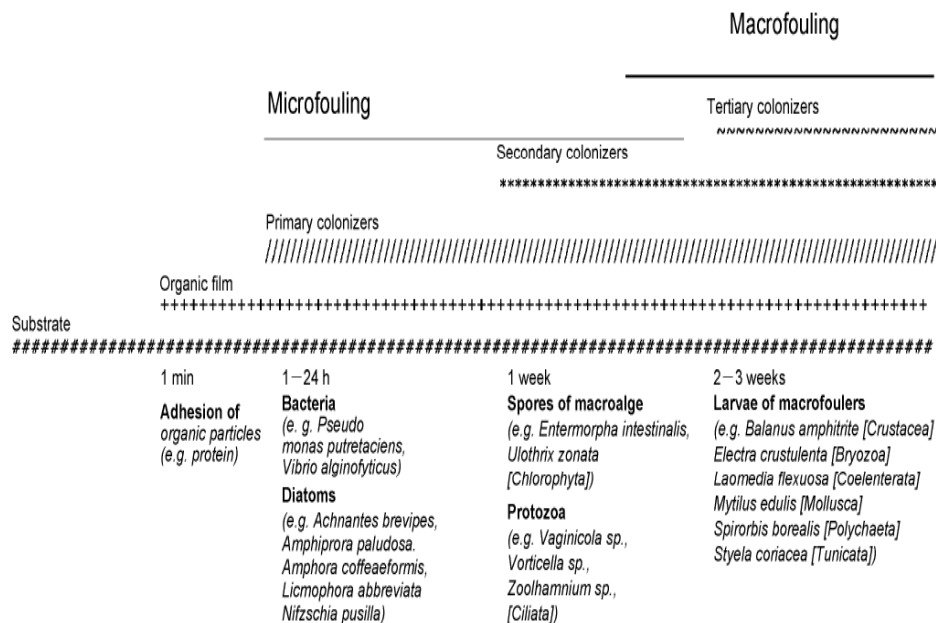
**Figure 18 *Bugula neritina***

(Source: California Academy of Sciences, 2011)

## **2.5 Adhesion Mechanism**

Most marine biofouling species live primarily in shallow waters along the coast and in harbors that provide ample nutrients. Microfouling or biofilm organisms and macrofouling organisms make up the two broad categories of marine adhesion organisms. The former is ubiquitous in nature upon exposure of surfaces to water; examples are bacteria and diatoms. The latter include organisms like algae and barnacles, but of importance are barnacles, bryozoans, seaweed and polychaete worms.

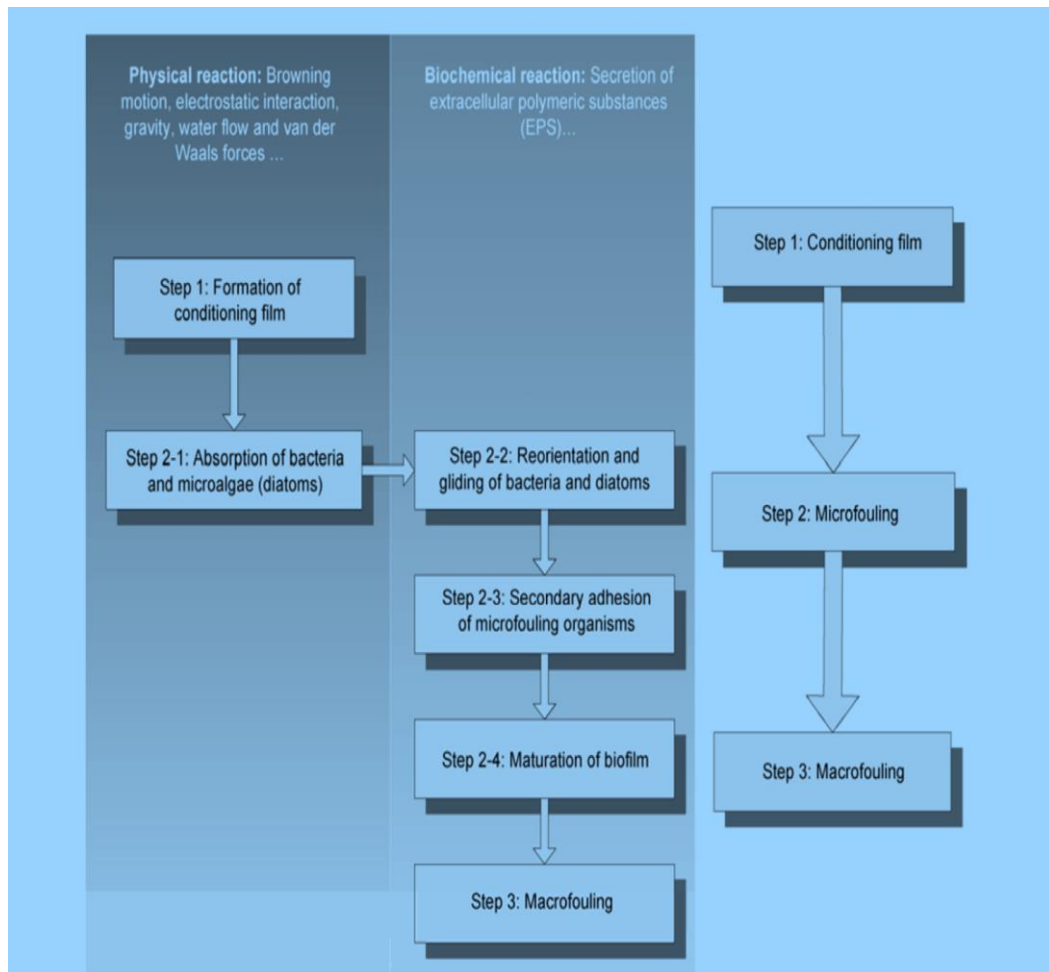
The process of biofouling begins through a physical reaction when a conditioning film made up of organic materials such as polysaccharides, proteins and proteoglycan, forms on the surface of the substrate. The conditioning film makes the surface sticky, thereby increasing the chances of adherence of microorganisms (see Figure 19). Organisms such as bacteria and microalgae then adhere to the surface, developing a biofilm. Diatoms are the most significant contributors to biofilm formation.



**Figure 19 Temporal settlement of fouling organisms on a substrate surface**

(Source: Cao et al., 2011)

There are two (2) distinct steps in microorganism colonization: reversible adsorption and irreversible adhesion. Physical effects like Brownian motion, van der Waals forces, electrostatic interaction, gravity and water flow govern the first step. On the other hand, the second step is governed mainly through biochemical effects like secretion of Extracellular Polymeric Substances (EPS). After the biofilm has been developed, macrofouling larvae or spores then attach to the surface and after two (2) or three (3) weeks, they evolve into a complex biological community. It is important to note that larvae of some species like bryozoans, polychaetes and other biofouling organisms adhere before the formation of biofilm. From the above, it is safe to say biofouling occurs by both physical (reversible) and biochemical (irreversible) reactions as seen in Figure 20. It is, therefore, easier to prevent biofouling during the physical reaction than during the biochemical reaction (Cao et al., 2011).



### Figure 20 Biofouling process and the formation of biofilm

(Source: Cao et al., 2011)

### 2.5.1 Bacterial Adhesion

This mechanism occurs when there is an interaction of planktonic cells with the surface by physical reactions such as gravity, water flow and electrostatic interactions. After absorption, bacteria uses extracellular polymers such as glucose and fructose-based polysaccharide fibrils in order to temporarily attach to the surface. A biofilm is then formed and after maturation, the cells are dispersed into the water for species expansion.

The system known as quorum sensing is applicable here as the bacterial cells have the ability to sense that they are part of a concentration of cells of a particular size called

the quorum. This they do by recognizing specific low-molecular-weight signal compounds which are secreted and accumulated by cells in the quorum. This system is vital for survivability of the cells.

The ratio of the extracellular compounds (mass of cells in biofilms, extracellular proteins, carbohydrates, glycoprotein, phospholipids, nucleic acid and other surfactants) excreted by several species is different. In fact, same species secrete diverse EPS compounds under different situations. The polysaccharides of these extracellular compounds are heterogeneous in nature, having different monosaccharide units and inorganic materials. The heterogeneity in the different biofilms makes broad-spectrum antifouling quite difficult.

### **2.5.2 Microalgae Adhesion**

The most dominant fouling organisms here are the diatoms. Other marine fouling eukaryotic microorganisms are fungi and protozoa. Unlike the adhesion process of bacteria, diatoms are more complicated because most of them do not possess a flagella and, hence, are unable to actively approach a surface, but land on the substratum in a passive manner. An example is seen when ‘benthic diatoms’ approach surfaces either through the effects of water currents or gravity. In the case of ‘plankton diatoms’, they land on surfaces through turbulence. This is because plankton diatoms have a similar specific gravity like seawater. It has been reported that van der Waals forces may also play a role in the contact process between diatoms and surfaces.

The next step after diatoms are able to land on surfaces is the active formation of an initial reversible attachment, otherwise known as primary adhesion via the secretion of EPS. This step is followed by a process known as ‘diatom gliding’. This they do by reorienting themselves and moving towards positions, depending on their preferences. If the diatoms continue with their life cycles in the same position after diatom gliding, there will be a formation of an irreversible secondary adhesion by the secretion of a large amount of EPS. The composition of EPS of diatoms is made up of carboxylated or sulfated acidic polysaccharides and proteoglycans. The former is involved in the

primary adhesion while the latter is involved in diatom gliding and cross-linking stabilization of the biofilm matrix.

There are different species of diatom and the EPS produced by them are diverse. In the same species of diatom, it is possible to detect at least two different types of mucilage. There are actually some features that are common among the diverse species of diatoms such as their general structural components by time of flight-secondary ion mass spectrometry (TOF-SIMS), and modular proteins and their supramolecular assemblies of adhesive nanofibers (ANFs). These features could be helpful in the fight against diatom adhesion.

### **2.5.3 Macro-organism Adhesion**

The colonization of macro organisms like the barnacle larvae, spores of macro algae, molluscs, bryozoans, tunicates, polychaete and coelenterates is the most challenging effect of biofouling.

One of the common characteristics of macro organism settlement is known as ‘Biofilm Cueing’. Initially, it was documented that an increase in the concentration of diatoms could cause the maturation of barnacle larvae. Experiments have now proven that biofilms do not aid the settlement of all macro organisms. There is a belief that microorganisms produce metabolites that help to repel specific macro organisms because of the competition for light and nutrients.

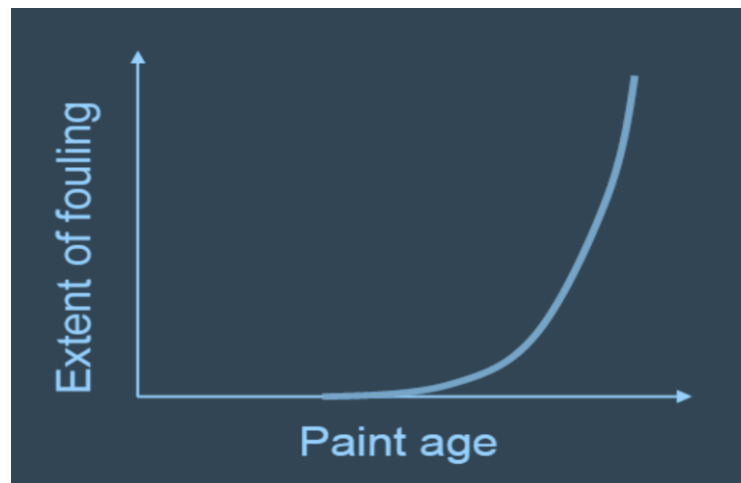
“Physiochemical Cueing” is another common characteristic of macro organism settlement. Experiments have indicated that invertebrate larvae are able to make use of water streaming properties in order to select suitable substrates. It is widely accepted that chemical cues originating from prey organisms, conspecific adults and substrates, facilitate the settlement and metamorphosis of larva.

Even though macro organisms settle based on the above ‘biofilm and physiochemical cues’, the mechanisms of adhesion are different for specific organisms (Cao et al., 2011).

## 2.6 Factors influencing marine growth on ship hulls

### 2.6.1 Characteristics of the ship

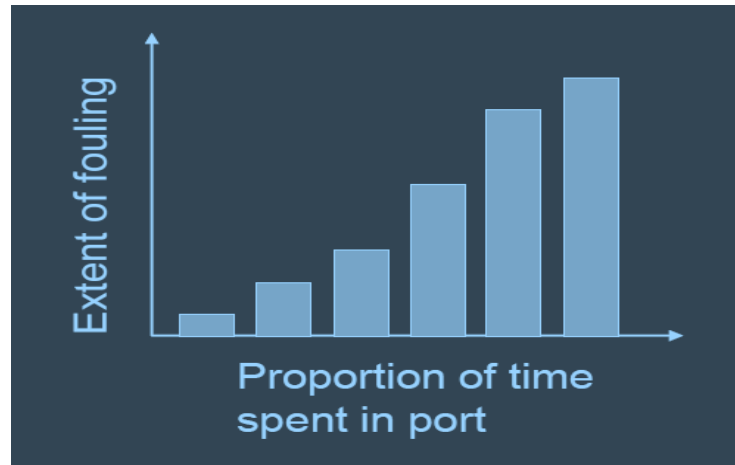
Antifouling paints contain biocides that are able to inhibit or kill invertebrates, larvae of plants and spores. Paint containing TBT used to be an effective antifouling toxin before its ban in 2008 after being discovered to deform oysters, cause sex changes in whelks and be harmful to marine life. Copper is also found to be toxic to marine life. The age of the paint on the vessel (as seen in Figure 21) is critical to its fouling level as old paints are not as effective and, therefore, prone to colonization. This is the reason why operators are expected to apply a renewal coating at appropriate intervals as specified in the AFS Convention.



**Figure 21 Effect of age of paint on fouling level**

(Source: Godwin, S. 2013)

Vessels that are very active show the effectiveness of antifouling paints more than vessels that are not active because fouling organisms find it more difficult to attach themselves to moving ships. Furthermore, there are more larvae/spores of organisms in coastal waters than in the open seas. From Figure 22, it is evident that the longer the resident time in port of vessels, the higher the level of fouling.

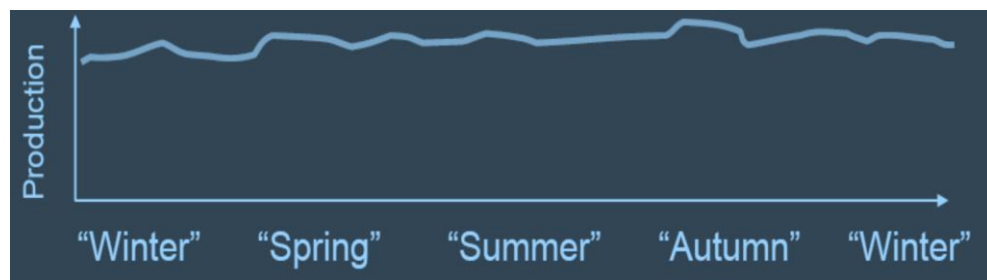


**Figure 22 Effect of resident time on fouling level**

(Source: Godwin, S. 2013)

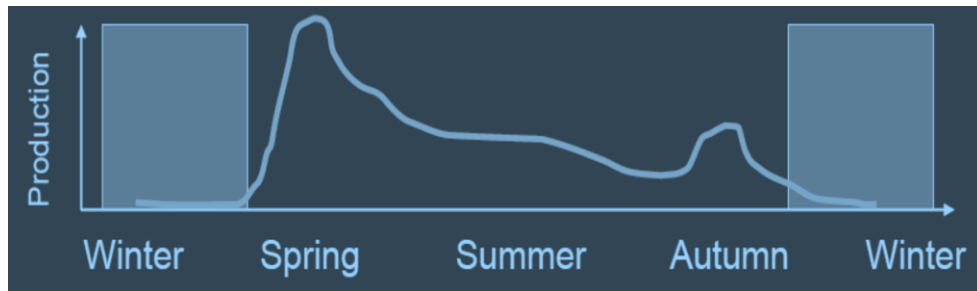
### 2.6.2 Characteristics of the Port Environment

Research has widely shown that fouling is more severe in tropical regions than in the temperate regions of the marine environment. This is because fouling propagules reproduce all year round in the tropics, whereas in the temperate regions, reproduction is higher in spring and autumn, and lower during winter (see Figures 23 and 24).



**Figure 23 Tropical Port**

(Source: Godwin, S. 2013)



**Figure 24 Temperate Port**

(Source: Godwin, S. 2013)

### **2.6.3 Biology of Fouling Organisms**

Ship hulls provide an enormous and diverse habitat for marine sessile organisms. An example of a sessile organism is the Bryozoan *Watersipora sp.* This organism establishes frequently on ship hulls and in port environments. While it has the ability to withstand copper better than other species, it can also be found on vessels that have recently been coated with a new antifouling paint. Through epibiotic relationship, it has the ability of facilitating the transportation of other taxa (Godwin, 2013).

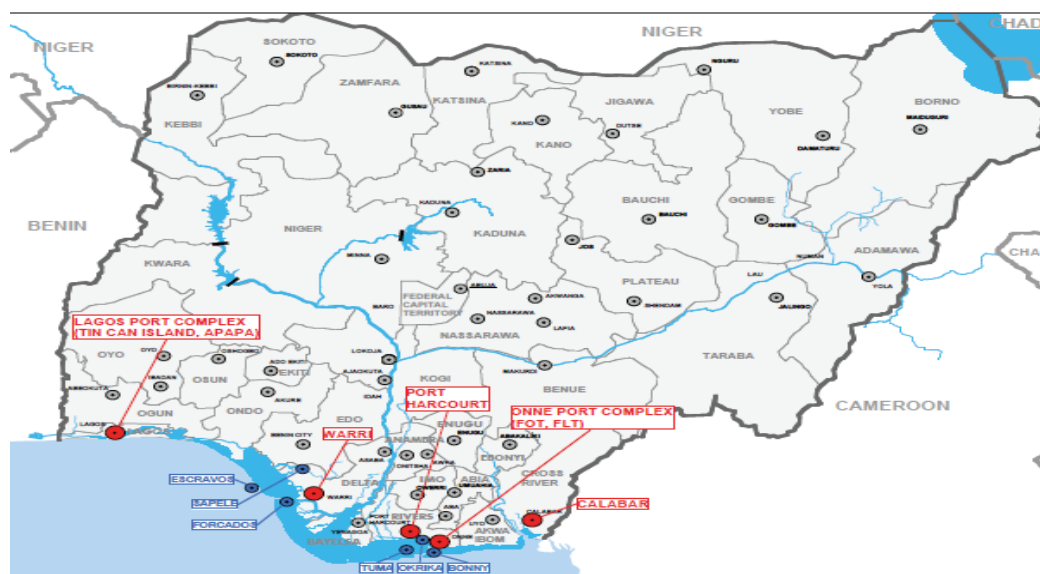


### **3 BIOFOULING IN NIGERIAN PORTS**

#### **3.1 The Nigerian Port System**

Nigeria is a littoral state with a coastline of about 853km and Territorial Waters of 12nm, Contiguous Zone of 24nm, Exclusive Economic Zone (EEZ) of 200nm and 10,000km of inland waterways. This area contains mineral resources including oil and gas deposits and installations which constitute the mainstay of the nation's economy. As a coastal state, Nigeria has jurisdiction over an extensive maritime area with significant living and non-living maritime resources (NMTP, 2016).

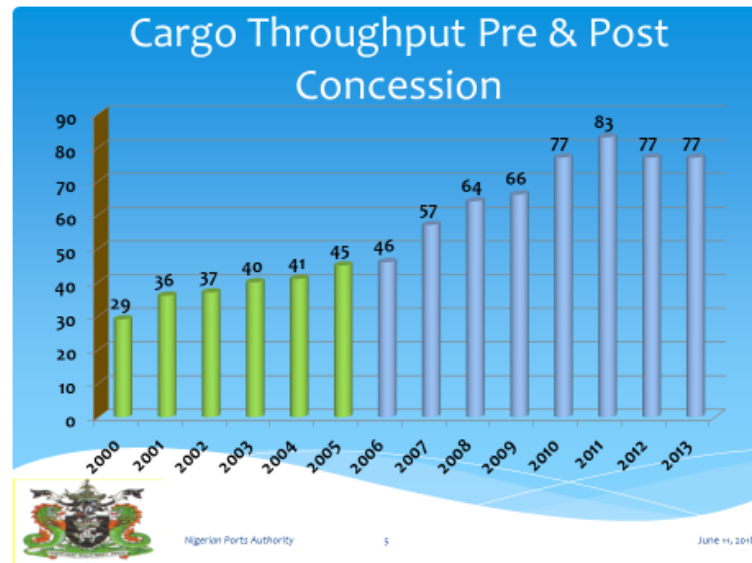
The Nigerian Ports Authority (NPA) is the government Agency responsible for the Nigerian Ports. It was established by the Nigerian Ports Act (1954) and saddled with the responsibility of 'development, ownership and operation of ports and harbours'; 'provision of safe and navigable channels'; 'ensuring safety and security of the ports'; 'offering cargo handling and storage services'; and 'maintaining port facilities and equipment'. At the moment, the NPA Act is undergoing a repeal at the National Assembly. NPA operates six (6) major ports namely: Lagos Port, TinCan Island Port, Rivers Port, Onne Port Complex, Calabar Port and Delta Port Complex as seen in Figure 25.



**Figure 25 Map of Nigeria Showing the six (6) major ports**

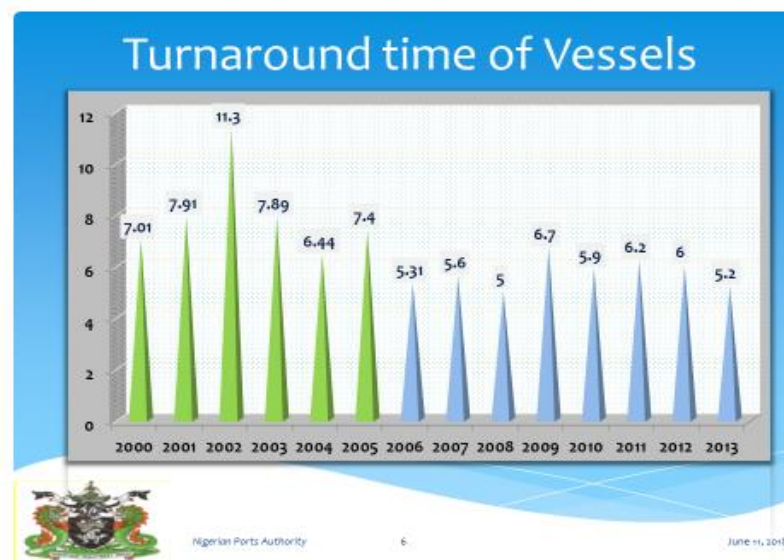
(Source: Federal Ministry of Transportation, Nigeria)

The Federal Government of Nigeria (FGN), in 2006, carried out a comprehensive “Port Reform” where it delineated the ports into twenty-six (26) terminals and concessioned them to private operators. The Reform also made NPA a landlord and technical regulator. In line with the concession agreements, the Terminal Operators are responsible for the entire cargo handling process and upgrade of terminals (FMT, 2013). The objectives of the Reform include, increase port efficiency, decrease port costs and attract private investments (Crown Agents, 2017). Figure 26 shows a remarkable improvement in cargo throughput after concessioning the ports to private operators. In the same vein, Figure 27 shows an obvious decrease in the turnaround time of vessels. The importance of turnaround time in the shipping business is very critical and thus, cannot be overemphasized. A decrease in turnaround time contributes to the ease of doing business. It is more cost effective and allows goods to be traded globally in an efficient manner.



**Figure 26 Cargo Throughput (Pre and Post Concession)**

(Source: Nigerian Ports Authority, 2013)



**Figure 27 Turnaround time of vessels (Pre and Post Concession)**

(Source: Nigerian Ports Authority, 2013)

### **3.2 Exposure of Nigerian Ports to Biofouling**

Analysis of Nigeria's ship traffic, tonnage, cargo throughput and trading partners will help in assessing if, and how exposed Nigeria is to invasive species.

#### **3.2.1 Statistics of Maritime Traffic**

As seen in Figure 26, the Cargo Throughput, as reflected in Table 2, increased after the 2006 Port Reform in Nigeria. With the Presidential Order on the Ease of Doing Business at Nigeria's seaports, ship traffic, tonnage and cargo throughput will show a rising trend. The Order to streamline the number of Agencies operating at the ports will eventually result in the achievement of 24-hour cargo clearance. Patronage will be attracted to Nigerian ports because, before now, ship owners preferred their ships to go to neighbouring ports because of the bottlenecks and longer turnaround time experienced in Nigerian ports. Statistics on ship traffic as seen in Table 1 does not reflect any significant increase but the full implementation of the Ease of Doing Business and the construction of the proposed deep sea port(s) in Nigeria will cause a tremendous positive change. This will mean that larger and more ships would be calling at the Nigerian ports and it an established fact that the increase in port capacity leads to a higher exposure level to biofouling. Furthermore, when the period of loading and unloading increases as a result of larger size of vessel and cargo, the likelihood of the fouling organisms attached to the hull of the vessel to be introduced to a recipient port remains high. It is important that Nigeria is ready for an increase in the ship traffic in order to prevent an inflow of invasive species. As global ship traffic has been on an increasing trend, so has the rate of unintentional species introduction into new marine environments. When these species are introduced, they establish in their new environment, competing with native organisms and eventually becoming residents.

**Table 1 Ship Traffic and Tonnage for the period of 2015 to 2017**

LOCATION	2015		2016		2017	
	NO	GRT	NO	GRT	NO	GRT
LAGOS PORT COMPLEX	1,410	36,290,502	1,183	33,503,583	1,151	31,932,784
TIN CAN ISLAND	1,656	45,864,565	1,529	44,227,295	1,350	41,477,915
DELTA PORT	528	5,822,393	314	4,997,148	312	5,277,722
RIVERS PORT	373	5,423,002	669	39,802,364	681	42,818,946
ONNE PORT COMPLEX	741	44,053,589	206	4,142,830	174	3,880,058
CALABAR PORT	306	3,796,652	469	6,800,324	507	6,182,396
<b>TOTAL</b>	<b>5,014</b>	<b>141,250,703</b>	<b>4,370</b>	<b>133,473,544</b>	<b>4,175</b>	<b>131,569,821</b>

Source: Nigerian Ports Authority

**Table 2 Cargo Throughput for the period of 2015 to 2017**

LOCATION	2015	2016	2017
LAGOS PORT COMPLEX	21,348,402	19,055,385	18,909,238
TIN CAN ISLAND	16,258,937	15,316,244	15,520,925
RIVERS PORT	4,457,785	3,546,745	3,462,425
ONNE PORT COMPLEX	26,572,745	23,896,730	25,836,246
CALABAR PORT	2,129,813	2,277,477	2,159,099
DELTA PORT	7,554,876	6,726,511	6,015,333
<b>TOTAL</b>	<b>78,322,558</b>	<b>70,819,092</b>	<b>71,903,266</b>

Source: Nigerian Ports Authority

Though there is a lack of empirical evidence showing the relationship between the success of invasion and maritime activities, predictive invasion models submit that an

increase in maritime activities such as shipping, increases the probability of the success of biological invasion (Lacoursiere-Roussel et al., 2016). According to Lockwood et al., 2009 (As cited by Lacoursiere-Roussel et al., 2016), the number of invasive species in any given area is a function of the number and abundance of the invasive species being introduced. This means that the pressure of the species colonization influences its invasion success. The establishment of an invasive species in a region is dependent on factors such as its interaction with environmental conditions and characteristics of the species. The greater the propagule number, the greater the chance of successful invasion as the intra-population density may be altered. This means that the genetic diversity will most likely decrease from native ranges to invasive ranges. However, some studies such as Kelager et al., 2013 and Roman & Darling, 2007 (as cited by Lacoursiere-Roussel et al., 2016) have stated that a single introduction of species could occasionally lead to a successful invasion. It is pertinent to determine the rate at which shipping influences invasion success as this could be useful in the management of Invasive Aquatic Species (IAS).

Nigeria, as a consumer country, has been heavily dependent on the importation of basic goods from other countries. These goods come into the country mainly through shipping routes. Aside from weakening the country's supply capital, it paves the way for an increase in the number of invasive species through biofouling. As biofouling remains an area which is lacking when it comes to research and management in Nigeria, the exposure level remains high and rising. It is therefore necessary to have a record of an up-to-date database where ship characteristics such as ship type, port of origin, residence time of vessels and other vital factors can be stored in order to understand the risk of introduction and management of invasive species.

### **3.2.2 Trading Regions**

Shipping remains the most important mode of transportation of international merchandise trade both now and most likely in the future. Both exports and imports exposes a country to invasive species. It is important to bear in mind that non-merchant ships, fishing vessels and recreational boats which are not covered by the AFS Convention, are also possible routes by which invasive species are transferred.

While it is true that Nigeria's importation rate is high, it is also true that Nigeria, as the largest Oil and Gas producing nation in Africa and the 6<sup>th</sup> largest oil producer worldwide, exports a lot of its oil to other regions as shown in Table 3. Although Nigeria exports its crude oil, the country still depends on other countries for importation of refined petroleum. Therefore, one way or the other, trading occurs with other countries and Nigeria's exposure rate keeps increasing.

**Table 3 OPEC Members Crude Oil Exports by Destination**

**1000 b/d**

	<b>Destination</b>	<b>Year</b>				
		<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>
		<b>2,368.0</b>	<b>2,193.0</b>	<b>2,120.1</b>	<b>2,114.0</b>	<b>1,738.0</b>
<b>Nigeria</b>	<b>Europe</b>	744.0	965.0	968.9	992.3	611.5
	<b>North America</b>	1,224.0	395.0	74.2	83.6	307.1
	<b>Asia and Pacific</b>	91.0	373.0	558.0	550.3	489.4
	<b>Latin America</b>	206.0	263.0	248.4	209.1	81.3
	<b>Africa</b>	103.0	197.0	270.6	278.7	248.7
	<b>Middle East</b>	-	-	-	-	-

Source: OPEC, 2017

In the course of exportation, the vessels used remain a medium for transport of organisms that are able to survive the conditions of the sea before arrival at their destination. Organisms from Africa and Asia will most likely thrive on arrival to Nigerian waters due to similarities in climatic conditions such as temperature.

Trading partners are one pathway for species introduction, with the exception of countries with strict biofouling laws. New Zealand, for example, is the first country to

insist that vessels coming into its waters must have clean hulls; otherwise, they face the risk of being hindered from entering the country's ports.

According to a review carried out by Abdulla & Linden (2008) on biodiversity in the Mediterranean, it was established that 29% of the vessel transported invasive species recorded were from the Indo-Pacific Ocean, 17% from pantropical and 14% from the Indian Ocean. The Indian Ocean, the 3<sup>rd</sup> largest of the world's oceans, is bound on the west by Africa and, in the summer, the western Indian Ocean is host to one of the largest concentrations of phytoplankton blooms. It was also shown that although most species in the Mediterranean are thermophilic, they originated from tropical waters. An example is the Asian date mussel which is found in most localities of the Mediterranean. Furthermore, the reports indicate that the number of invasive species introductions have been on the rise and this may be attributed to economic, political and societal changes.

As indicated earlier regarding exposure of Nigeria due to oil exportations, the development of oil fields in the middle east and globalization of trade have increased the pathways of introduction. There was a decline of species introduction in the 80's which was attributed to the closure of the Suez Canal to maritime traffic around 1967 and 1975.

### **3.3 Vulnerability of the Nigerian Ecosystem to Biofouling**

In order to determine the vulnerability of the Nigerian Ecosystem to biofouling, it is important to look into biofouling in other tropical regions. This is because invasive species established in one tropical region, have the tendency of establishing in another tropical region due to similar favourable climatic conditions, especially if these countries are trade partners.

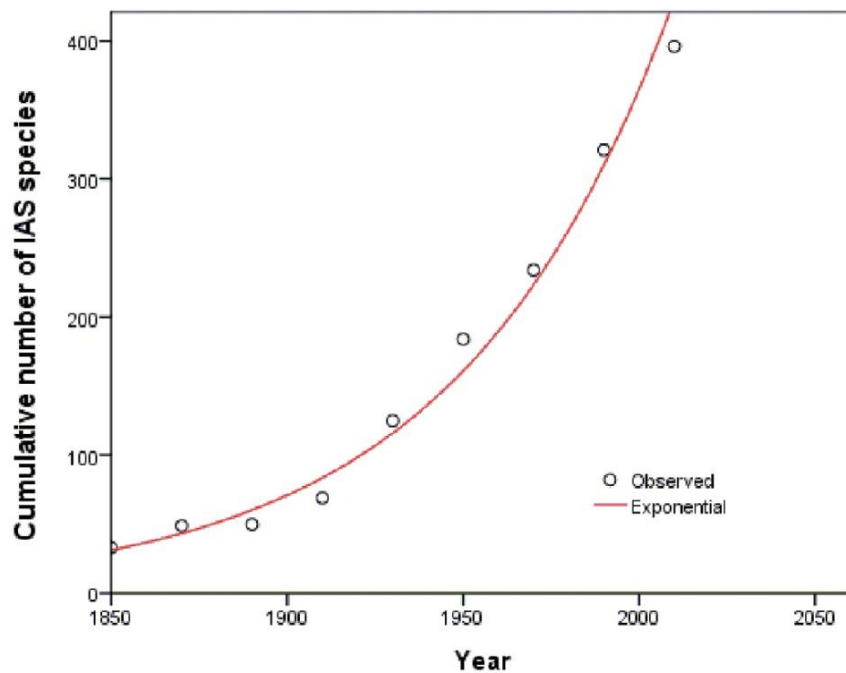
#### **3.3.1 Invasive Species in other Tropical Regions**

Not much is known about the rate, number of invasions and species diversity in the tropical regions of the world.

- a) **Temporal trends of invasive species in China:** Figure 28 indicates an exponential growth of Invasive Aquatic Species (IAS) in China. China is a vast



territory, which has more than one climate because of its different geographical regions. It could be tropical, subtropical, warm temperate, middle temperate or cold temperate. According to DAISIE, 2009 (As cited by Xu et al., 2012), China is seriously affected by invasions with a higher pace of increase than that which is recorded in Europe. From the research, it was reported that the fast economic growth experienced in China, and the increasing levels of tourism, transportation and trade will likely cause the country to face huge problems from invasive species in the future. Furthermore, the data of IAS from Europe and China suggests that the same trends will likely occur in other countries that are also experiencing fast growing economies. This imposes serious threats to global biodiversity and ecosystem services (Xu et al., 2012).



**Figure 28 Temporal trends of invasive alien species in China**

(Source: NeoBiota Article, 2012)

Cumulative numbers of first detected IAS in China (exponential growth:  $R^2=0.981$ ,  $P<0.001$ ;  $N=396$  IAS with known year or period of first detection in China) were

analyzed. Only 33 IAS occurred in China before 1850, and 53.5% of the IAS were recorded after 1950.

**b) Fouling load in a tropical Indian harbour:** Biofouling, as a global phenomenon in the marine environment is an acute problem in tropical waters rather than temperate waters because of the continuous ability to breed and recruit fouling organisms in warm temperatures. As a tropical nation, India experiences a high degree of fouling activities virtually along all its shores all year round. Essential quantifiable knowledge such as numerical abundance, biomass, density, and growth are necessary in order to estimate fouling potential of a given area. This will help in the control and management of fouling organisms. In any case, the buildup of biomass is a more reliable way of indexing the development of fouling.

The Visakhapatnam harbour of the Andhra Pradesh State of India was studied between 2007 to 2009 to quantify fouling load on a temporal and spatial scale. The harbour is known to be a water body full of pollution, usually as a result of eutrophication. The slipway complex, marine foreman jetty and ore berth of the harbour were sampled on wooden test panels of *Pinus roxburghii* (for yearly observations) and *Bombax ceiba* (for monthly observations). The wet weight of the accumulated fouling on each panel was taken in a bid to quantify the fouling load.

The results indicated that the yearly fouling load was higher at the ore berth and marine foreman jetty than in the slipway complex. On the other hand, the monthly maximum fouling level was higher at marine foreman jetty, followed by ore berth, reasons being that *Mytilopsis sallei* (an invasive bivalve) were heavily recruited in the marine foreman jetty, while barnacles were recruited at the ore berth. Lighter organisms such as serpulids and sabellids were recruited at the slipway complex. Fluctuating results were indicative of sloughing off of some organisms such as bryozoans and hydroids, which have short life cycles (Pati & Rao, 2015).

**c) The risk of invasive species due to the expansion of Panama Canal:**

According to Muirhead and Noble (2014), the opening of the Panama Canal in 1914 not only minimized transit time for ships, but also increased the likelihood of the spread of invasive species. Theoretically, it was possible for species to migrate between the Pacific Ocean and the Caribbean Sea via the canal but at the center of the canal is the freshwater of Gatun Lake, which blocks the migration of many marine species. They also explained that the expansion of the canal to support larger vessels could cause a change in species introduction in the following ways:

- The post-panamax and new-panamax ships would have a shorter voyage route. In relation to biofouling, movement through freshwater in the canal may limit survival of marine organisms;
- Post-panamax vessels will have many choices of trading ports. The probability that a species will survive in a port becomes greater when environmental conditions of the source and recipient port are similar. This is known as ‘environmental matching’. Environmental matching is, therefore, higher with the visit of new ports;
- With the increase in capacity of the canal and consequent increase in port capacity, there will be an increase in the number of ships arriving at some ports. This tends to lead to a higher exposure level of the port to invasive species, thereby leaving the port at risk; and
- The change in the types of vessels arriving at a port may have an influence on the likelihood of invasions. When the period of loading and unloading increases as a result of larger size of vessel and cargo, the likelihood of the fouling organisms attached to the hull of the vessel to be introduced to a recipient port remains high.

**d) A rapid assessment on Bivalve molluscan species in the tropical port of Kaohsiung in Taiwan:** Kaohsiung port is one of the largest ports in the world known for transportation of international cargo and containers (Munchin et al.,

2016). According to Liu et al., 2014 (As cited by Minchin et al., 2016), the likelihood of the port to act as a receptor area for non-indigenous species is due to its large volume of global ship traffic. Bivalve molluscan species have been noted to be successful global invaders, which continue to spread to ports worldwide. The biological traits (byssus) allow the bivalve to attach to the hulls of ships, especially slow moving vessels, thereby transferring the species from one port to another. Furthermore, the ability of byssate molluscs to feed on Seston also contributes to the success of the global invasion (Minchin et al., 2016). According to ISSG (As cited by Minchin et al., 2016), the byssate mollusc species are known to be among the worst invasive species due to their ability to spread rapidly within eutrophic waters and also their impacts on the environment and severe economic impact. IMO, 2007 (As cited by Minchin et al., 2016) indicates that these species have the ability to damage the environment, human health, resources or properties and they are defined by a specific port, state or biogeographic region.

- e) **A study on the management of risks of non-indigenous marine species transfer in Singapore using a study of vessel movement:** Lim, Leong & Tan (2017) carried out a study using two relevant factors to assess the risk of non-indigenous marine species transfer on vessels in Keppel Terminal: the vessels' residence time and the vessels' last port of call. The study reported that the uptake and transfer of biofouling species is associated with a longer vessel residence time in port. The vessels' last port of call (in this case, the majority were from Southeast Asian Ports) provided a clue to the biogeographic spread of species which the vessel had been exposed to. The information will allow port inspectors to assess a vessels risk level for adequate precautionary measures.

**3.3.2 Conclusion:** In conclusion, it is safe to say that the Nigerian ecosystem is vulnerable to biofouling. The trend of invasive species in the tropical countries above shows that the species that thrive in these countries will adapt in Nigerian waters. As Nigeria is in the process of developing new deep sea ports to accommodate larger vessels and foster trade, it is expected that the volume of trade will increase and exposure level to invasive species will also be higher. It is therefore imperative to have measures in place to prevent the spread and establishment of invasive species.

## **4 CONSEQUENCES OF INTRODUCTION OF INVASIVE SPECIES IN NIGERIA**

### **4.1 Marine Fouling in the Guinea Current Large Marine Ecosystem (GCLME)**

Millions of people in the world depend on the natural resources of Large Marine Ecosystems (LMEs) for food security, tourism, transport and income amongst others. It is estimated that LMEs contribute approximately USD\$28 trillion to the global economy on an annual basis. The sustainability of LMEs is dependent on changes in natural resources and human activities on both land and sea. As the global ocean is warming up, it is expected to impact both negatively and positively on marine ecosystems. In the Transboundary Waters Assessment Programme (TWAP) of 2016, using biophysical indicators and all the LME's human developmental status, it was discovered that developing countries of Africa and Asia are more at risk of environmental impacts and severe human consequences. The coastal populations in the more populated regions in the tropics are at higher risk due to a combination of factors such as their dependence on the resources of the LME, effects of environmental threats and low capacity in terms of adaptation level. The assessment also stated that the ocean health of LME's in the tropical regions should be given higher priority (IOC-UNESCO & UNEP, 2016).

Biodiversity and seasonal conditions influence the process of marine growth colonization, making it difficult to quantify. To address this difficulty, it is important to construct models of biofouling and make forecasts over a long period of time. It is also pertinent to continue researching the phenomenon behind the dynamics of the growth of marine fouling organisms. Biofouling is significant in the Gulf of Guinea because the environment is very favourable for marine growth all year round. A study was carried out to assess marine growth dynamics on four (4) sites for exploration and

production of the Total Oil Company. It was discovered that there were significant differences in the colonization process of the dominant species in the different regions that were analyzed in the Gulf of Guinea. Environmental parameters (such as water currents, waves, availability of nutrients and physico-chemical parameters of the sea), depth of the water, the geographical area of the exploitation sites, installation platforms and human activities were the determining factors in the nature of colonization.

In essence, when a structure is immersed in the sea, it is fouled rapidly. There are quite a number of marine growths that are found in the Gulf of Guinea, as well as other regions of the world on offshore structures. This is because there are species that are influenced by temperature and salinity and not geographical location.

In the Gulf of Guinea, Barnacles and Corals are the major hard fouling organisms seen. Geographical factor is not a limitation to the proliferation of Barnacles. Corals, on the other hand, grow better in favourable environmental conditions such as warm seawater temperature, abundance of nutrients and intense wave action. The major soft fouling organisms in the Gulf of Guinea include bryozoans, brown and green seaweeds, and hydroids. They are found in all depths of water, thereby colonizing all maritime regions. Temperature and salinity have no influence in their geographical distribution (Boukinda Mbadinga et al., 2007).

Judging from the above, it is evident that Nigeria, being in the Gulf of Guinea, is prone or exposed to fouling. This means our vessels and other visiting vessels, especially those that are resident in a particular place for days or more, are highly exposed to marine fouling organisms.

## **4.2 Impacts of Biofouling**

The impacts of marine invasive species can be categorized into three (3) types: Ecological Impacts, Economic Impacts and Health Impacts.

### **4.2.1 Ecological impacts**

When species are introduced into a new environment and become invasive, initially the impacts are almost invisible or minor but when the population of the species increases, the impacts become more visible. Ecological impacts of invasive species

could be quite complex, occurring when the indigenous biodiversity or ecological processes are altered by the invasive species. Some of the impacts include competition with indigenous species for food and space; habitat alterations; food web alterations; preying on the indigenous species; change in environmental conditions; inducing local species extinction; reduction in native biodiversity; and displacement of indigenous or native species.

According to Strayer and Malcom, 2007 (As cited by GISP, 2008), Zebra mussels invaded the Hudson River in North America, leading to a rapid decline of all the native bivalve species between 1992 and 1999, by competing with the natives for food and smothering/fouling of the native species (GISP, 2008).

#### **4.2.2 Economic impacts**

The economic implication of fouling on a ship's hull cannot be underestimated, owing to the increase in fuel cost associated with it and also the cost of prevention, management and control. When a ship's hull is fouled, its hydrodynamic drag is increased and maneuverability decreased, thereby increasing the rate of fuel consumption. In shipping, fuel cost constitutes about 50% of the total operational costs. Fouling is said to increase annual consumption of fuel in commercial shipping by 40%. It therefore remains worthwhile to invest in cleaning programmes of the hull and coating of the vessel using antifouling paint. Microbial Induced Corrosion can occur when there is fouling. This can happen when sulphides are produced by sulphate reducing bacteria that causes pitting of steel surfaces (GISP, 2008). At the moment, Nigeria has no cleaning programmes.

Fouling may deteriorate the coating of a vessel, leading to corrosion of the hull prematurely (Kovanen, 2012). Fouling also influences the costs of shipping indirectly. Once a vessel is fouled by marine organisms, attempts are usually made to eradicate or manage and control them. It is estimated that over \$15 billion annually goes into controlling fouling in piping systems, water intakes and heat exchangers of desalinization and power plants. Moreover, over 1 billion Euro is spent annually on controlling fouling of the membranes used for wastewater and desalinization systems.



The impact of fouling on Aquaculture occurs when invasive species settle on the farmed species or infrastructure such as ropes, net cages, buoys, and platforms, leading to increased maintenance costs and labour costs. When invasive species settle on these infrastructure, water flow is reduced through the nets and trays, reducing production levels. The farmed species could be attacked by the introduction of parasites and pathogens, which affects the health of the cultured species, leading to a reduction in productivity (GISP, 2008).

#### **4.2.3 Health impacts**

Unfortunately, not much attention is paid to the role that biofouling plays in the spread of diseases. Some documented diseases include infectious salmon anaemia, amoebic gill disease affecting cultured salmon, white spot virus affecting shrimps and bonamiosis spread through oysters on barges in the United Kingdom. It is also reported that molluscs found frequently on ship's hulls may be responsible for the transfer of parasites between different cultured species or populations, especially those that are close to the ports (GISP, 2008).

#### **4.3 Impact of fouling on vessels' energy efficiency**

The cumulative carbon dioxide (CO<sub>2</sub>) emissions resulting from shipping are estimated at 2.2% of global emissions, although, according to the Energy Transitions Commission in 2017, the figure is likely to increase because of the constant growth of international trade and a gradual reduction of CO<sub>2</sub> (de-carbonization) in land transportation than in shipping. That being said, shipping is still considered the most energy efficient mode of transportation as compared to road, rail and air transport. As fuel costs constitutes about 50% of total operational costs in shipping, the IMO in 2015, estimated that about 201 to 272 million tonnes of fuel was consumed annually in the period from 2007 to 2012, giving rise to over \$80 billion/year for shipping's fuel bill (Adland et al., 2018).

Bouman et al. (2017) carried out a review of different technologies for improving energy efficiency in shipping, including low carbon content fuel (e.g. biofuel or liquid natural gas), renewable energy sources (e.g. solar or wind energy), or the use of emission reduction technologies (e.g. propulsion system or power). At the end of the

review, the authors concluded that the reduction of Green House Gas (GHG) emissions by 50-60% per freight unit transported with newer technologies is possible/attainable by the year 2050. In 2011, IMO adopted the Ship Energy Efficiency Management Plan (SEEMP) to formalize the significance of operational measures. The plan mandates all ship owners to have in place a formal system for the management and optimization of ship and fleet performance. The key measures of operation include reduction in speed, periodic cleaning of the hull and its propeller, and weather routing. Furthermore, Jensen et al. (2018) continued by stating that when you raise crew awareness (by training using simulators), approximately 10% of fuel consumption can be saved. The less fuel consumed, the less CO<sub>2</sub> will be emitted.

As earlier stated, when marine organisms attach to the hull of a vessel, they drag the vessel, making it heavy and slow in movement, thereby leading to more fuel consumption and, consequently, more CO<sub>2</sub> emissions. The need for cleaning, therefore, cannot be overemphasized. Adland et al. (2018) explains that there are at least two (2) reasons for cleaning vessels' hulls to reduce emissions and increase energy efficiency. First, is because hull fouling has become a huge factor contributing to an increase in the rate of emissions and, secondly, it remains the main driver over which a ship owner has an enormous degree of control because the ship owner can make a decision to adhere to periodic maintenance of the hull and its propeller.

There are two (2) types of hull cleaning methods; first is underwater hull cleaning which involves divers mechanically removing marine growth from the hull with powered brushes. This method remains the cheapest and fastest method of the two. The second is cleaning when the vessel is in dry-dock for a survey as specified by the flag state or classification society, which is every fifth year after delivery of the vessel. Dry-docking usually costs a lot of money. Adland, et al. (2018) made use of available empirical fleet performance data and weather data to measure the impact of the two hull maintenance types (underwater cleaning and dry-docking) on energy efficiency. At the end of the analysis, the following deductions were made: daily fuel consumption is reduced significantly with periodic hull cleaning; dry-docking by far (17%) leads to

a greater reduction in fuel consumption compared with normal underwater cleaning (9%); and the impact of hull cleaning is greater reflected on energy efficiency when the vessel is sailing laden than when the vessel is carrying ballast. In addition, a simulation exercise was carried out to confirm reduction of fuel consumption after cleaning operations. Such detailed information needs to be taken into consideration when developing policies for Nigeria's cleaning programmes since no programmes are currently documented.

#### **4.4 Risk Assessment**

##### **4.4.1 Vessels residence time**

The amount of time a vessel remains in port is known as its residence time. The longer a vessel's residence time, the better the chances of potentially invasive species attached to its hull have to spread and increase in range. Residence time incorporates some factors that may directly affect the 'propagule pressure', which are the amount, the frequency and timing of reproductive material getting to a new area and disseminating there. They may also affect the success of an invasive species being naturalized. Residence time is, hence, one factor influencing invasiveness through anthropogenic factors and biological traits (Wilson et al., 2007). Commercial shipping vessels are the most productive long distance anthropogenic mechanism of transferring non-indigenous species on a wide scale, causing invasions by a diversity of invasive organisms (Davidson et al., 2018).

As far back as 1985, Carlton (As cited by Lim, Leong & Tan, 2017) discovered and reported that a shorter vessel duration or stay in port led to a reduced ship biota (biofouling), which was a result of efficient port handling. As part of its vessel management strategies, "Craft Risk Management Standards" in New Zealand makes use of residence time in port as a criterion for inspection for determining an acceptable clean vessel hull. The term 'turnaround time' (the time a vessel arrives a port, load, unloads or undertakes servicing operations to the time it departs the port) can be used to determine port efficiency index as well as residence time (Lim, Leong & Tan, 2017).

#### **4.4.2 Vessels' last port of call**

The biogeographic origin of a vessels' last port of call is very vital in assessing the risks of invasive species by hull fouling. In a study carried out by Seebens et al., 2013 (As cited by Lim, Leong and Tan, 2017), the focus was on vector-based modeling where trade patterns, differences in temperature and salinity, and biogeographic distribution were used as models for bioinvasion probability. The results showed that Singapore and South-East Asian regions were bioinvasion hotspots. In essence, it could be implied that vessels trading from Asia to Nigeria or vice versa will most likely be fouled and, therefore, caution should be taken to minimize the transfer of invasive species.

During a Global Invasive Species Programme (GISP), it was reported that there were about 55 invasive species (with the exception of indigenous species) that had spread to other countries from Singapore. Out of the species discovered, the *Mytilopsis sallei*, belonging to the bivalve mollusc species, previously discussed in Chapter two (2) of this dissertation, was found to be prominent in tropical countries. This goes to show that there is a possibility that Nigeria, in one way or the other, either directly from Singapore or from vessels that had visited Singapore and ended up in Nigeria, has the probability of harbouring this particular species in its waters.

Spalding et al., 2007 (As cited by Lim, Leong and Tan, 2017), classified different marine eco-regions of the world, which can be used for identification of shipping routes noted to have high vessel arrivals and also for identification of vessels departing marine eco-regions that are known to high records of invasive species.

#### **4.5 Justification**

Several reports such as those documented by Hulme et al. (2013) and cited by Havel et al. (2015), indicate that more research has been undertaken in temperate regions than in the tropics. This has led to very poor knowledge of the species found in the tropical regions. It is also documented that tropical freshwater communities are likely to lose more species than temperate regions when there are invasions because the tropical regions are richer in species diversity.

## **5 CONTROL AND MANAGEMENT MEASURES**

### **5.1 International Convention on the Control of Harmful Anti-Fouling Systems on Ship, 2001 (AFS Convention)**

“The International Convention on the Control of Harmful Anti-Fouling Systems on Ship” (AFS Convention) was adopted on the 5<sup>th</sup> of October, 2001 at the Headquarters of the International Maritime Organization (IMO) in London. The Convention aims at the protection of the marine environment and human health from adverse effects of Anti-Fouling Systems (AFS) on ships (IMO, 2007) by prohibiting the use of harmful organotins which act as biocides in anti-fouling paints, and establishing a mechanism for prevention of potential future use of other harmful substances in anti-fouling systems (IMO,2018).

Anti-fouling paints are coatings used at the bottoms of ships aimed at preventing marine life such as algae and molluscs from attaching to the hull of the ship and leading to hydrodynamic drag (slowing down the ship), and thereby increasing fuel consumption. Back in the days of sailing ships, lime and later arsenic were used for coating of ships' hulls. Metallic compounds were later used to develop anti-fouling paints by modern chemical industries. These metallic compounds began leaching into the sea water, killing marine life including barnacles that get attached to the vessel. Studies showed that these compounds also persist in water, harm the environment and possibly enter the food chain. The organotin, tributyltin (TBT) was one of the effective compounds used in anti-fouling paints since the 1960's. It was then proven that TBT was responsible for sex changes in whelks and deformations in oysters.

The above-mentioned discovery was the driving force for the international community to adopt the AFS Convention in 2001. The Convention came into force on the 17<sup>th</sup> of

September, 2008, 12 months after 25 states, representing 25% of the world's merchant shipping tonnage had ratified it (IMO, 2007). Nigeria acceded to the AFS Convention in 2003 and it has since been domesticated into the country's National Law as documented in the Merchant Shipping (Anti-Fouling Systems) Regulations, 2012 under the guidance of the maritime administration known as the "Nigerian Maritime Administration and Safety Agency" (NIMASA). The Honourable Minister of Transport made the declaration by the powers conferred on him by sections 335(1) and (3), and 434 of the Merchant Shipping Act, 2007.

The AFS Convention applies to ships of 400 Gross Tonnage and above which are Nigerian ships, non-Nigerian ships but operating under the Nigerian authority, or ships which do not fall into the former or latter but are in a port, dockyard, shipyard or jetty in Nigeria or in an offshore terminal in Nigerian waters. The Convention obliges those in charge of shipyards or ship repair facilities to collect, handle, treat and dispose of any wastes originating from the application or removal of anti-fouling paints, in a safe and environmentally sound manner in order to ensure protection of human health and the environment. An authorized person shall on behalf of the Agency (NIMASA), communicate to the Organization (International Maritime Organization, IMO) the details, such as the powers and responsibilities of the surveyors or Recognized Organizations (RO's) authorized to act in the administration on the control of anti-fouling system related matters. Any approval, registration and licensing of AFS in Nigeria must be communicated by the manufacturers to any party on their request. Information protected by Law must not be disseminated to any party by the manufacturers.

On surveys and certification, a ship of 400 Gross Tonnage and above must have an initial survey before it is put into service or before the AFS Certificate is issued for the first time. If an AFS is changed the ship must be surveyed and this survey shall be validated on the Certificate. Both surveys (initial and replacement of AFS) shall show if the ship's AFS is compliant with the AFS Regulations, and such surveys shall only be done by surveyors or officers that are authorized by the Agency. If an authorized

officer or surveyor appointed by the Agency discovers that a vessel's AFS is not in conformity with the AFS Regulations, the officer shall inform the Agency and the Agency will either ensure that corrective actions are taken or certificate is not issued or is withdrawn as the case may be. However, if the ship is registered in a country other than Nigeria, the Agency shall inform the authorities of that country as to the action taken.

It is important to note that there are ships of 24 meters or more in length but less than 400 Gross Tonnage that are engaged in international voyages. In such cases, the ships are issued with a "Declaration" on AFS which must be signed by the owner or his agent. Relevant documentation such as invoice of the contractor or paint receipt must be attached to the Declaration. When a ship is in a Nigerian port, shipyard or offshore terminal, a qualified person shall inspect it to ensure compliance with AFS Regulations. The inspection includes verification of a valid AFS Certificate or Declaration on AFS, and sampling of the AFS. If it so happens that the ship is found to have violated the AFS Convention, the ship can be detained but may be allowed to proceed to sea only with the intention of proceeding to a nearby repair yard. If a ship is detained, the owner or master of the ship is served with a notice of detention stating the grounds that led to the detention and the requirements to be complied with for release of the ship. If the detained ship is not a Nigerian ship, the Agency shall inform the consulate or diplomatic representative of the State that the ship is flying its flag or the maritime authority of the State. With regard to sampling of AFS to determine its compliance, the Agency is obliged to establish a laboratory with up-to-date diagnostic and analytic equipment (MSR, 2012).

## **5.2 Overview of IMO's 2011 Guidelines for the Control and Management of ships' biofouling to Minimize the transfer of invasive species**

On the 15<sup>th</sup> of July, 2011, the IMO adopted the "Guidelines for the Control and Management of ships' biofouling to minimize the transfer of invasive species". The Guideline notes that the AFS Convention helps in preventing adverse impacts that may result from the AFS and the biocide that could be contained in it, rather than preventing the transfer of invasive species in the marine environment. It also notes that every ship

has some degree of fouling irrespective of whether they have recently been cleaned. Biofouling is said to be influenced by factors such as design/construction of the ship, operating profile (such as speed, location when not in use), trading routes and places visited, and maintenance history.

This Guideline aims at providing a global and consistent method/approach for the management of biofouling. It is expected to be refined when advances on scientific and technological aspects are made in order to better address the risks. It provides important recommendations on measures for minimization of biofouling risks and it is up to the States to determine how the Guidelines will be applied. Other recommendations in the Guideline are for every ship to maintain a biofouling management plan (in order to have effective procedures for biofouling management) and a record book. Biofouling management measures are expected to be outlined in the biofouling management plan while records of the biofouling management practices are expected to be stored in a biofouling record book. The biofouling management plan should include details such as the AFS, treatments in use, inspection and hull areas that are susceptible to biofouling, amongst others. The plan is expected to be updated when necessary. The biofouling record book, on the other hand, will keep record of inspections and management measures taken on a ship. A State is able to carry out potential risk assessment of a ship using the record book. This is because it contains information such AFS details, date and place of dry-docking or in-water inspections.

The Guideline also explains that there are different AFS, which are designed for different ships depending on the profile of operation. Therefore, it advises ship designers, ship builders and ship operators to seek technical advice for the purpose of ensuring the right AFS is applied. Furthermore, it explains the considerations to note for installation, re-installation and repair of the AFS especially in niche areas in order to ensure good adhesion and durability of the AFS.

The process for ship maintenance and recycling facilities, in-water inspection, cleaning and maintenance, design and construction, information dissemination, training and education are all clearly spelt out in the Guideline. It is expected that when



all the management practices are implemented, the transfer of invasive species will be minimized (IMO, 2012).

The IMO supplemented this Guideline with the introduction of the “Guidance for minimizing the transfer of invasive aquatic species as biofouling for recreational crafts”. This was approved at the Marine Environment Protection Committee (MEPC)’s sixty-fourth (64<sup>th</sup>) session in 2012 through circular “MEPC.1 Circ.792”. This is to target recreational crafts that are less than 24 meters long and act as significant vectors in the transfer of invasive species. Similarly, the IMO through its MEPC at its sixty-fifth (65<sup>th</sup>) session in 2013, approved a “Guidance for evaluating the 2011 Biofouling Guideline”. The justification for this Guidance rests on the expectation that technological and scientific advances will be made, thereby initiating a review. This Guidance will, therefore, assist States and observers wanting to gather information and make necessary reviews in a consistent manner. It is equally important to note that the implementation of the Biofouling Guidelines is being supported through technical cooperation programmes by the IMO’s Integrated Technical Cooperation Programme (ITCP). The activities aim at raising awareness on biofouling and also understanding/being familiar with the Guideline for global implementation (IMO, 2017).

### **5.3 IMO’s GloFouling Project**

Following the Global Environment Facility, the United Nations Development Programme and the International Maritime Organization (GEF-UNDP-IMO)’s GloBallast Programme on ballast water management, which was launched in 2007 and successfully completed in 2017 (GloBallast Partnerships, 2017), the IMO is in the process of launching a new project on biofouling. The initial commencement of the project, which began in 2017, is aimed at building capacity in developing countries in order to implement the 2011 Biofouling Guidelines and thereby protect marine ecosystems in a globally consistent manner (IMO, 2017). The project will prevent or minimize environmental and economic damage to mariculture, fisheries, and coastal infrastructure, amongst others, which contribute to the livelihood of coastal

communities (The Maritime Professional, 2017). It is also expected to contribute to global shipping GHG emission reduction (UN, 2017).

Implementation is expected to begin from September, 2018 and last for a five-year period (IMO, 2017). As done in the GloBallast Project, this project will run as a collaboration with the GEF, UNDP and IMO (IMO, 2017).

The project is tagged “Building Partnerships to assist Developing Countries to Minimize the Impacts from Aquatic Biofouling”, otherwise termed “GloFouling Partnerships”. Nigeria was one of the lead partnering countries in the second phase of the GloBallast Project and it is, therefore, important to note that Nigeria will also be part of the GloFouling Project. The GEF-UNDP-IMO collaboration will be driven on a three-tier implementation model to drive legal, policy and institutional reforms. It will also encourage transfer of technology through Public-Private Partnerships (PPP) at global, regional and national levels (MarEX, 2017).

It is pertinent to note that the Institute of Marine Engineering, Science & Technology (IMarEST) was highly active in the GloBallast Project in terms of capacity building, especially in the technical guidance activities. They intend to replicate this towards the success of the GloFouling Project (The Marine Professional, 2017). At the Sustainable Ocean Summit of 2017 in Halifax, Canada, it was highlighted that the GloFouling Project will bring together maritime administrations, academia, shipping industry and technology developers to discuss the best way forward and how technology transfer can be achieved (UN, 2017).

#### **5.4 Ships’ Hull Cleaning**

About 80% of an entire ship hull and all sea adherences are required to be cleaned before embarking on inspection (Akinfiev, Janushevskis and Lavendelis, 2015). A ship’s performance is at jeopardy if its hull is fouled because a heavily fouled vessel is generally slow and consumes more fuel as a result of the hydrodynamic drag caused by the fouling organisms attached; its engine wears faster than a vessel with a clean hull, and charter agreements are usually not met, amongst others disadvantages. Similarly, according to GloMEEP (2018), when the buildup of fouling is prolific and

made up of hard foulers like barnacles and/or tubeworms, there is a possibility of causing turbulence, noise and cavitation, thereby affecting speed logs, performance of sonars and other sensors.

The interval between cleanings and inspections varies depending on the vessel type, geographical location of the vessel, the vessel's service profile, including speed, residence time and the type/condition of bottom coatings. When a large vessel is involved, it is expected to have some layers of coating and it is thus advisable to have its hull cleaned after every 4-6 months of operation. In terms of geographical location, more frequent cleaning is required of vessels plying tropical waters because the rate of fouling of marine organisms is more evident due to warm favourable climatic conditions. In the U.S. for example, the Navy has established fouling zones according to geographical regions, noting the frequency for cleaning operations. In some cases, cleaning is done 3 to 6 times annually (Akinfiev, Janushevskis and Lavendelis, 2015).

Cleaning can be done at dry dock or what is known as underwater hull cleaning. The latter tends to be a more economical way of cleaning for ship owners. Underwater cleaning can be done either by the use of a Remotely Operated Vehicle (ROV) as seen in Figure 29 or with the help of a diver using brushes (GloMEEP, 2018).



**Figure 29 Diver performing underwater hull cleaning**

(Source: GloMEEP, 2018)

### **5.5 The Need for Policy Development on Biofouling in Nigeria**

As one of the major threats to global biodiversity, biofouling also needs to be tackled at Country level and, as such, Nigeria is due to put in place regulatory frameworks in order to control or manage the spread of invasive species. A strategy document with action plans and implementation plans, as well as timelines needs to be developed. Similarly, regional strategies should be developed for a more coordinated approach in addressing the menace of biofouling. Nigeria, as an Economic Community of West African States (ECOWAS) member and also a member of some regional bodies, participates in regional partnerships such as the GEF/UNIDO Guinea Current Large Marine Ecosystem and Abidjan Convention in the protection of the marine environment and the use of marine resources in a sustainable manner. In essence, the national, regional and international systems will eventually be harmonized in the achievement of a common goal through coordinated efforts. The Nigerian Maritime Administration and Safety Agency (NIMASA), mandated to protect the marine environment amongst other mandates, should be the lead agency in the establishment of a national legislation on biofouling. Other relevant stakeholders can be drawn from the other maritime agencies (such as the Nigerian Ports Authority, National Inland Waterways Authority, Maritime Academy of Nigeria), environmental sector, academia, maritime training institutions, and port users, amongst others. It is imperative that the responsibilities of each stakeholder are clearly spelled out to avoid overlapping functions and conflict of interests.

It is pertinent to note that places like Australia, California and New Zealand have begun implementation of requirements beyond the minimum guidelines specified by IMO. The Australian Government Initiative on the management of biofouling aims at helping operators of commercial vessels in minimizing risks of invasive species. The guideline contains procedures and information to assist commercial vessel operators in preventing invasive species introduction. Also contained in the guideline are management and treatment options (treatment of hull, niche areas-areas not protected by antifouling coat, and internal seawater systems) (Commonwealth of Australia, 2008).

The State of California tagged its program as California's Marine Invasive Species Program (MISP). It specifies that each operator must have a biofouling management plan and record book that is vessel-specific after delivery of a new vessel or after an existing vessel's scheduled dry-docking. This applies to vessels that are resident or anchored for 45 days or more. Furthermore, 24 hours before a vessel's first arrival at one of California's ports in a year, it must submit an "Annual Vessel Reporting Form" (IIMS, 2018).

The Ministry of Primary Industries in New Zealand tagged its program as 'Craft Risk Management Standard' (CRMS) on Biofouling and states that a vessel's pre-arrival details will be used to determine biosecurity risks. High risk vessels will need to tender their maintenance/hull cleaning records or have a dive inspection. If the rate of fouling is beyond the threshold allowed, the vessel will either be hauled-out and cleaned or cleaned under-water. All associated costs will be borne by the ship owner (MPI, 2018).

Nigeria needs to dedicate and apportion a cleaning zone so as to prevent further spread of invasive species or contamination of the environment in the process of cleaning the vessels. Similarly, there should be an approved cleaning technique(s) or accepted technologies with standardized facilities for ship's hulls and niche areas also. In setting up our national strategic framework, it is important to take into account scientific acceptability and the possibility of an economically feasible framework.

It is pertinent to take into consideration the risk assessment methods established by the International Organization for Standardization (ISO) – ISO 13073 series, as it particularly relates to AFS. These are in three parts as follows:

- Part 1: ISO 13073-1:2012 for risk assessment of biocidally active substances used for AFS on ships (ISO, 2012);
- Part 2: ISO 13073-2:2013 for risk assessment of AFS on ships using biocidally active substances (ISO, 2013); and
- Part 3: ISO 13073-3:2016 for human health risk assessment of biocidally active substances used in AFS (ISO, 2016).

The 2011 IMO Biofouling Guidelines should serve as a guide in the development of a national strategic framework but since IMO regulations are the basic minimum standards, Nigeria can raise the bar by taking a cue from Australia, the State of California and New Zealand for effective implementation.

## **6 RECOMMENDATION AND CONCLUSION**

Nigerian marine scientists need to carry out comprehensive studies on invasion patterns of species or the phenomenon behind the dynamics of the growth of marine fouling organisms that are prone to establishment in tropical waters, particularly in Nigeria. This will enable the prediction of potential invasions in the future and ensure adequate preparation of management practices and, by so doing, invasion rates will be minimized. Similarly, the different characteristics of invasive species and their adhesion mechanisms ought to be known for a better management strategy.

The importance of information on vessels movements such as speed, trading partners, ports of call, average residence time and geographic distribution of species in the diverse eco-regions cannot be overemphasized in drafting of policies. With these information, it is possible to assess the risk factors of the vessels that are likely to be heavily fouled and potentially invasive.

Mitigating the transfer of invasive species is equally important by taking proactive measures especially on vessels that are known to be from high-risk regions, while transiting through Nigerian ports and, while taking into account the risk assessment methods of the ISO as regards biocidally active substances, AFS and the human health risk of biocidally active substances in AFS. The continuous reduction of discharges into sea as a result of shipping operations, reduction of GHG emissions and enforcement of biofouling regulations will contribute to the achievement of the Sustainable Development Goals such as goals 7 (affordable and clean energy) and 14 (life below water).

A national instrument should be drafted solely for the protection of our marine environment from the risks of invasive species through biofouling. Biofouling

inspection needs to be of high priority in the tropical regions. Similarly, marine biosecurity policies are needed for effective management and prevention of invasive species. While regional cooperation needs to be reinforced in the management of invasive species, it is essential to actively participate in the United Nations Ocean Conferences as the IMO is currently focused on the development of a legally binding instrument that will be essential for the conservation and sustainable use of marine biodiversity beyond national jurisdiction.

In conclusion, the International Convention on the Control of Harmful Anti-Fouling Systems on Ship (AFS Convention), which is mandatory, and the Guidelines for the Control and Management of ships' biofouling to minimize the transfer of invasive species (recommendatory), ought to be abided by especially as regards having a biofouling management plan, a biofouling record book and a well-equipped laboratory for a more effective management of invasive species. A national regulatory framework to augment these regulations would boost Nigeria's control measures by preservation of its biodiversity, protection of human health, prevention of environmental pollution, reduction of GHG emissions and economic boost.



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## APPENDICES

### Appendix 1 Characteristics of Marine Fouling Species

Summary of relevant fouling organisms in tropical and temperate environments, and key target bioassay organisms

Relevant biofouling organisms	Common bioassay organisms	Environmental location
<b>MICROORGANISMS</b>		
<b>Bacteria</b> <i>Pseudomonas</i> <i>Vibrio</i> <i>Micrococcus</i> <i>Achromobacter</i> <i>Aeromonas</i> <i>Flavobacterium</i> <i>Roseobacter</i> <i>Alteromonas</i>	<i>Pseudomonas sp.</i> <i>Vibrio sp.</i>  <i>Shewanella sp.</i>	
<b>Cyanobacteria</b> <i>Leptolyngbya</i> <i>Rivularia</i> <i>Lynghya</i> <i>Synechococcus sp.</i>		Tropical
<b>Diatoms</b> <i>Navicula</i> <i>Nitzschia</i> <i>Cocconeis</i> <i>Licmophora</i> <i>Synedra</i> <i>Amphora</i> <i>Achnantes</i> <i>Bacillaria</i>	<i>Navicula sp.</i> <i>Nitzschia sp.</i>  <i>Amphora sp.</i>	Tropical  Tropical, Temperate

<b>Relevant biofouling organisms</b>	<b>Common bioassay organisms</b>	<b>Environmental location</b>
<i>Biddulphia</i> <i>Melosira</i> <i>Fragilaria</i> <i>Grammatophora</i> <i>Rhabdonema</i> <i>Berkeleya</i> <i>Amphora coffeaeformis</i> <i>Asterionella Formosa</i>	        <i>Cylindrotheca closterium</i>	        Temperate
<b>MACRO ORGANISMS</b>		
<b>Algae</b> <i>Ulva intestinalis</i> <i>Alaria esculenta</i> <i>Laminaria saccharina</i>	    <i>Ulva sp.</i>	    Tropical, Temperate
<b>Annelida</b> <i>Pomatoceros triqueter</i>	   	   
<b>Cnidaria</b> <i>Metridium senile</i> <i>Obelia longissimi</i> <i>Tubularia sp.</i>	    	    
<b>Mollusca</b> <i>Anomia ephippium</i> <i>Hiatella arctica</i> <i>Mytilus edulis</i>	    <i>Mytilus sp.</i> <i>Perna sp.</i> <i>Patella vulgata</i>	    Tropical, Temperate
<b>Barnacles</b> <i>Balanus sp.</i>	 <i>Balamus sp.</i> <i>B. Amphitrite</i>	 Tropical, Temperate Tropical, Temperate

<b>Relevant biofouling organisms</b>	<b>Common bioassay organisms</b>	<b>Environmental location</b>
<i>Semibalanus balanoides</i> <i>Elminius modestus</i>		
<b>Bryozoa</b> <i>Electra pilosa</i> <i>Membranipora membranacea</i> <i>Botrylloides leachi</i> <i>Bugula neritina</i>	<i>Bugula sp.</i>	Tropical, Temperate
<b>Asciidiacea</b> <i>Ascidia mentula</i> <i>Ciona intestinalis</i> <i>Ascidia elasp</i> <i>Styela clava</i>		Temperate

Source: Salta et al., 2009



## Appendix 2 Some examples of Microfouling and Macrofouling Organisms

		TYPES	EXAMPLES
<b>MICROFOULING ORGANISMS</b>		Sessile bacteria	Micrococcus, Pseudomonas
		Diatoms	Amphora spp., Navicula sp., Nitschia spp.
		Micro-fungi	
		Heterotrophic flagellates	Monosiga, Pteridomonas
		Sarcodines	
		Sessile ciliates	
<b>MACROFOULING ORGANISMS</b>	<b>Hard fouling</b>	Barnacles	Amphibalanus amphitrite, Amphibalanus reticulatus, Balanus amphitrite
		Bivalves	Crassostrea gigas, Mytilus spp., Perna canaliculus, Perna perna
		Calcareous tube worms	Hydroides albiceps, Hydroides elegans
	<b>Soft fouling</b>	Algae	Laminaria spp. (brown alga) Enteromorpha spp., Ulva spp. (green algae) Ahnfeltia spp. (red alga)
		Anemones	Haliplanella sp.
		Ascidians	Didemnum vexillum
		Bryozoans	Bugula neritina, Cryptosula pallasiana, Watersipora subtorquata, Zoobotryon pellucidum
		Corals	
		Hydroids	Obelia sp.
		Sea cucumbers	
		Sponges	Acanthella cavernosa

Source: Bouyssou & Madjidian, 2013

**Appendix 3 Species introduced by Biofouling and included in IUCN's 100 Worst Invasive Alien Species**

<b>Species</b>	<b>Area and mechanism of introduction</b>	<b>Impacts</b>
The European shore crab or green crab – <i>Carcinus maenas</i> .	Native to Europe and northern Africa, it has been introduced to Australia, South Africa and the USA by a variety of pathways including hull fouling	It is a voracious predator and has caused the decline of other crab species and some bivalves.
The Mediterranean mussel ( <i>Mytilus galloprovincialis</i> ).	Native to the Mediterranean, Black and Adriatic Seas, it has established in mainly temperate areas around the globe – mostly near ports. Hull fouling and ballast water were the most common pathway.	Outcompetes and displaces native mussels, and has associated impacts on the entire benthic community.
Asian kelp ( <i>Undaria pinnatifida</i> ) into the Mediterranean, Australia and New Zealand.	Introduced to the Mediterranean with oysters, but via hull fouling and/or ballast water to the coastal waters of Argentina, Australia, New Zealand and North America.	Heavy infestations of <i>Undaria</i> slow the growth of mussels, and foul finfish cages, oyster racks, scallop bags and mussel ropes, which impact on the mariculture industry.

Source: Global Invasive Species Programme (GISP), 2008

#### Appendix 4 Controls on Anti-Fouling Systems

Anti-fouling system	Control measures	Application	Effective date
Organotin compounds which act as biocides in anti-fouling systems	Ships shall not apply or re- apply such compounds	All ships	1st January, 2003
Organotin compounds which act as biocides in anti-fouling systems	Ships either: <ul style="list-style-type: none"> <li>• shall not bear such compounds on their hulls or external parts or surfaces; or</li> <li>• shall bear a coating that forms a barrier to such compounds leaching from the underlying noncompliant anti-fouling systems</li> </ul>	All ships (except fixed and floating platforms, FSUs and FPSOs that have been constructed prior to 1st January, 2003 and that have not been in dry-dock on or after 1 <sup>st</sup> January, 2003)	1st January, 2008

Source: MSR, 2012